THE PLANT ECOLOGY

OF THE DUNE SYSTEM ON KAITORETE SPIT

A THESIS PRESENTED
FOR THE DEGREE OF M.SC. IN BOTANY
IN THE UNIVERSITY OF CANTERBURY
CHRISTCHURCH, NEW ZEALAND

BY

PEACE, M.

1975.

CONTENTS

SUMMARY

page

INTRODUCTION 1

CHAPTER ONE

1. GEOMORPHOLOGY AND HISTORY OF KAITORETE SPIT 2
2. THE NATURE OF THE DUNES 4
3. RECENT HISTORY AND MANAGEMENT 7

CHAPTER TWO

CHOICE OF SITE FOR STUDY AND OUTLINE OF PROCEDURE. 9

CHAPTER THREE

THE ENVIRONMENT. 11

1. SOILS 11
   (a) Soil Types
   (b) Soil Texture and Organic Matter . . 13
   (c) Soil Moisture 16
   (d) Soil Nutrients and Soil Reaction. . 23
2. SAND MOVEMENT 25
3. CLIMATE 29
   (a) Temperature and Humidity. 29
   Dew and Soil Water Vapour 38
   (b) Precipitation 40
   (c) Wind 42
   (d) Evaporation 45
   (e) Sunshine 48
   Observations about the Climate in General 49
4. Influence of Animals 51

CHAPTER FOUR

THE VEGETATION 54

1. (a) General Description 54
   (b) Relict Trees and Shrubs 57
2. (a) Selection of Communities for Study. 59
   (b) Vegetation Analysis 60

page

(c) Flora and Vegetation of the Selected Communities, indicating Seasonal Changes. 64

3. Observations on Morphology and Phenology of the Dune Species 73

(a) Morphology. 74

(i) Aerial Shoots. 74

(ii) Roots and Rhizomes 75

(b) Phenology 79

(i) Observations on Seedlings of some Indigenous Species. . . . 79

(ii) Observations on Growth Rates of some Indigenous Species . . 81

(iii) Summary of Phenology 84

CHAPTER FIVE

RESPONSE OF PLANTS TO THE ENVIRONMENT. 86

I ATTRIBUTES OF THE DUNE SPECIES

1. Morphology and Physiology 87

(a) Aerial Shoots 87

(b) Roots and Rhizomes 90

2. Phenology

(a) Vegetative Activity 92

(b) Reproductive Activity 92

II PLANT DISTRIBUTION ON THE DUNES

1. Zonation 96

2. Succession 100

3. The Vegetation Prior to Polynesian Settlement 103

CHAPTER SIX

GENERAL DISCUSSION AND CONCLUSIONS 108

SUGGESTIONS FOR FURTHER STUDY 112

ACKNOWLEDGEMENTS 113

APPENDICES page

APPENDIX I SOIL DATA 114

APPENDIX II CLIMATE DATE 121

APPENDIX III PLANTS 140

REFERENCES 144

SUMMARY

In a two-year study of the ecology of the dune system of Kaitorete Spit, work has been concentrated on a number of distinctive plant communities associated with specific land-form units. Throughout one whole year, at frequent intervals, systematic measurements were made of environmental factors affecting the dune area as a whole, and also within the selected communities. Parameters measured included rainfall, wind, evaporation, humidity, temperatures of the air, ground surface, and soil at various depths, and soil moisture content at various depths. Physical characteristics of soils, and sand movement were studied. For nearly two years observations on the plants were recorded, including floristic composition of the communities and their seasonal changes, and morphological and phenological attributes of most of the indigenous and adventive species.

An attempt has been made to evaluate the influence of environmental factors on plant forms, phenology and plant distribution.

Investigations have revealed that the Kaitorete dunes represent an extremely harsh environment for plants on account of the combination of very low rainfall, very high summer temperatures, low humidity for much of the year, strong winds, salt spray, and very low water-holding capacity of the substrate. Nevertheless, the area supports a remarkable group of plants, among which the indigenous species in particular are strikingly adapted to survive and to provide permanent ground cover, if not subjected to the additional pressures of fire and browsing animals.

It is considered that deterioration of the vegetation has probably been in progress for several centuries, partly as a result of the Polynesian occupation; changes have almost certainly been accelerated during the past hundred years of European settlement. Some conservation measures are warranted for an area of such unique botanical interest.

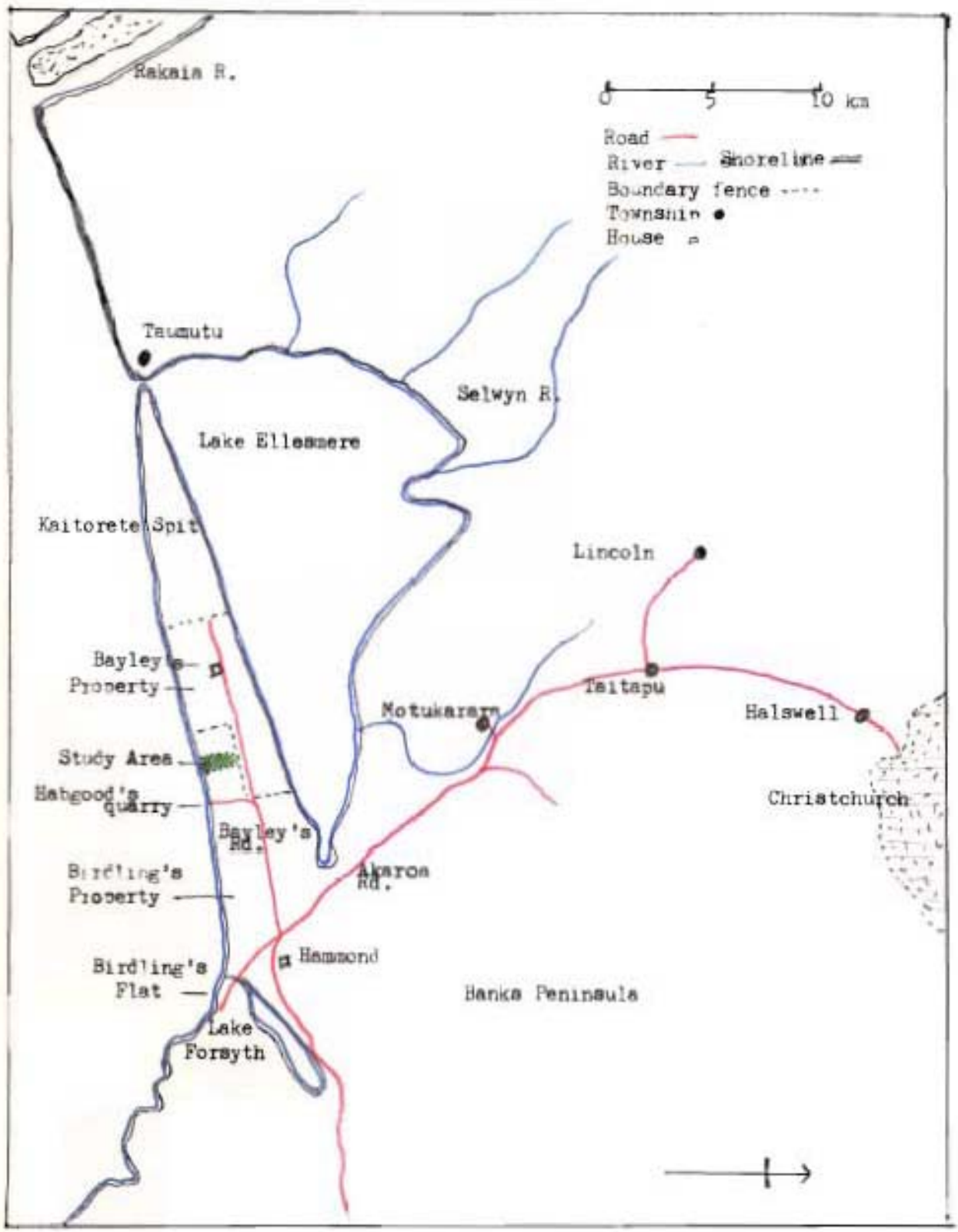


Fig. 1. Kaitorete Spit and environs.

INTRODUCTION

Kaitorete Spit, also known as Ellesmere Spit, is situated Lat. 43°47' - 43°51'S, Long. 172°22' - 172°41' E, lying south-west of Banks Peninsula. From the north-east end, near Lake Forsyth, to the south-west end at Taumutu, it extends about 28km in length; its width ranges from 3.2km in the east to about 100m in the west; its area is about 4855 hectares (Fig. 1).

The Spit is basically a gravel ridge, with a general height from 4 - 6m above m.s.l. On the seaward side the gravel is covered by sand dunes, ranging from small mounds in the east to a height of 16m in the west.

This dune system appears to be unique, to the extent that there is no other sizeable area of comparable geomorphology in New Zealand, although smaller areas of sand over shingle occur at the mouths of the Wangaehu and the Wairau Rivers. It is also one of the increasingly rare localities round the New Zealand coast where the dominant sandbinding species is the endemic Desmoschoenus spiralis (pingao), which elsewhere has generally been replaced by the introduced Ammophila arenaria (marram grass).

Casual observation suggested that this was an area in which a number of environmental factors were likely to be operative in producing an ecological situation different in many respects from any described in sand dune studies elsewhere, either in New Zealand or overseas, e.g. Cockayne (1911), Logan and Holloway (1934), Esler (1970), Salisbury (1925 and 1952), Oosting and Billings (1942), Wright (1956), Olson (1958), Willis et al (1959 and 1960), Wilson (1960), Ranwell (1958, 1959, 1960).

The present study attempts to evaluate the significance of environmental factors in relation to the flora and vegetation, including species distribution, and seasonal growth patterns, on the dunes of Kaitorete Spit.

CHAPTER ONE

GEOMORPHOLOGY AND HISTORY OF KAITORETE SPIT

1. ORIGIN AND CHANGES IN SHORELINE

Armon (1970) has described the Spit as originating from a barrier beach, built against the coast south-west of Banks Peninsula, and consisting of gravel deposits derived chiefly from the Rakaia River. Referring to investigations by Suggate (1958, 1963) he suggests some time between 6000 and 7000 years BP for the final development of the barrier which led to the enclosure of Lake Ellesmere. * There is evidence that sea levels may have been up to 5m higher than at present, and higher levels certainly existed in Lake Ellesmere. Closing of the sea access to Lake Forsyth has occurred only in recent times, since Maori canoes and small schooners were able to enter through an open channel at the time of early European settlement (Burrows, 1969a).

Coastal erosion has been active at the western end for a considerable time, culminating in the opening up of sea access to Lake Ellesmere at Taumutu. Maori tradition records the loss of a pa, Te Rangitamu, by sea erosion, in this locality several centuries ago. At the present time, connection between Lake Ellesmere and the sea occurs periodically near Taumutu, when very high tides occur, or when an artificial cut is made to prevent the lake level from rising more than 1m above m.s.l.

Armon (1970) considers that the shoreline currently shows recession west of Taumutu, and accretion in the Birdling's Flat region, while there is an area extending for about 11km east of Taumutu where a constant shoreline has existed for a considerable period of time, apart from slight possible retreat.

From aerial photographs taken of this coastline in 1971, by Mr F.E. McGregor of the Botany Department of the University of Canterbury, it appears that erosion is active

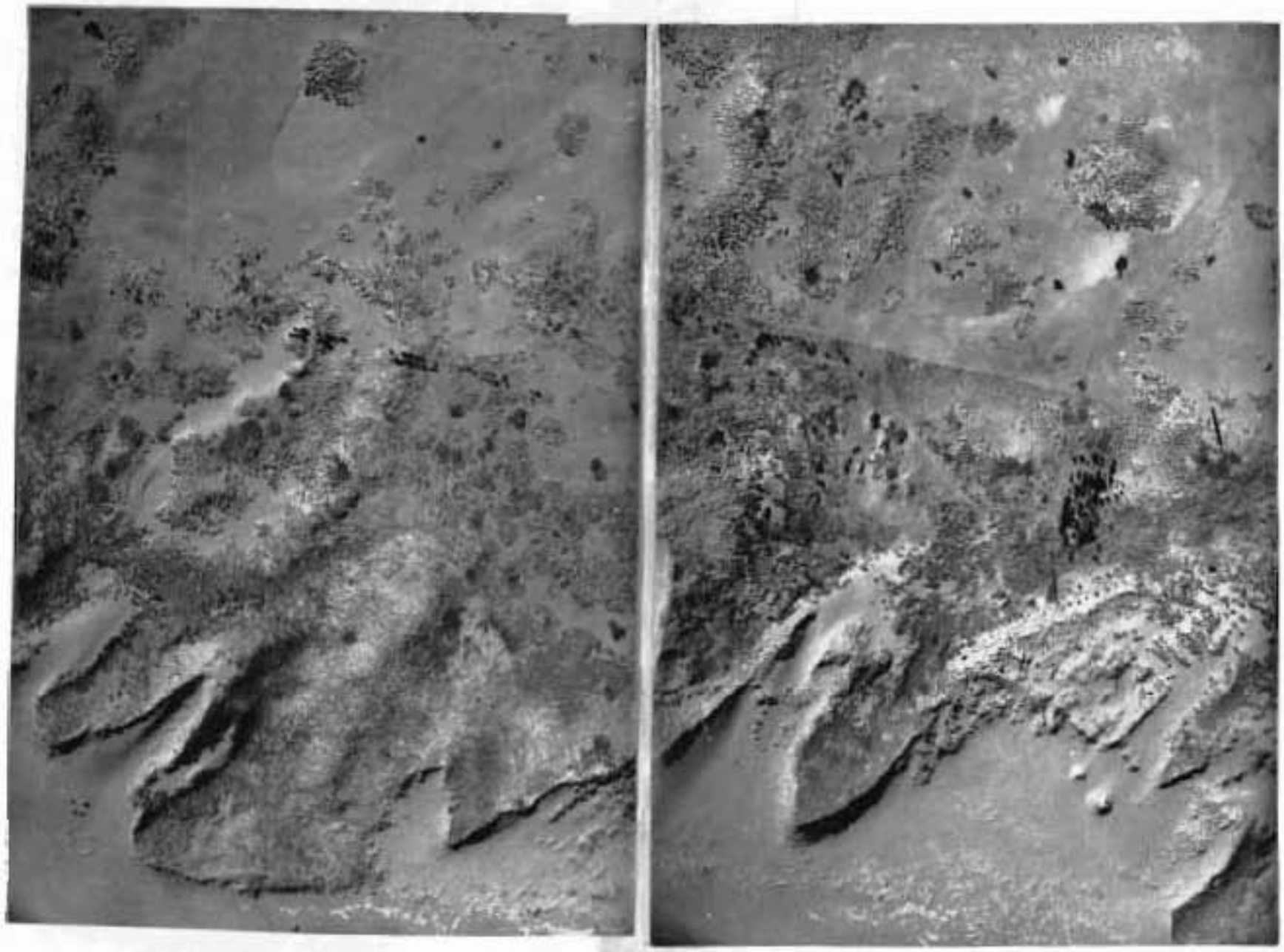


Fig. 2.

Aerial view of dunes opposite Bayley's homestead.

Note rows of pine trees on seaward side of fence line.

Scale 1:1500 approx.

along the entire western half (14km) of the Spit, where wave-trimmed seaward faces of the dunes are obvious (Fig. 2).

Near Bayley's homestead, during a southerly storm in mid-winter of 1971, waves were seen to wash high up between the dunes, 30m or more inland from their seaward extremities, undermining slopes that had been long stabilised by shrubby vegetation. Mr Bayley (pers. comm.) has noted the removal of about 25m from the seaward end of his western boundary fence, over the past twenty to thirty years.

photo 3b
fits here
↓

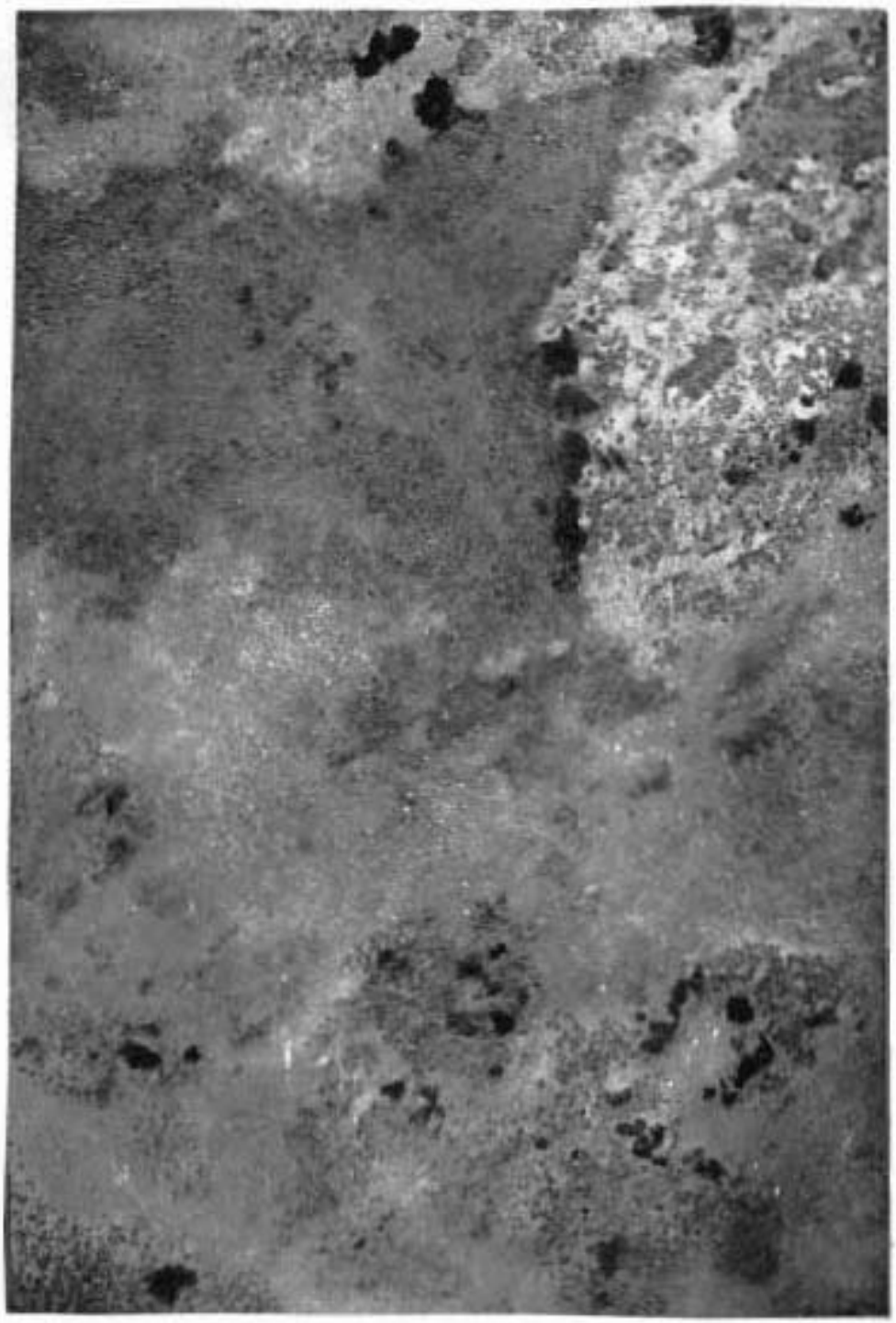
←station C.

←station B.

←station A.

Fig. 2 a.

Study area showing microstations A, B C; also the adjacent blowout to the west.
Strandline just visible at lower edge of photos.
cf. Figs 4 and 5.
Scale 1:1500 approx.



station E.

station D.

Fig. 3b. Study area showing microstations D and E.
This photo fits against upper right edge
of photo 3a.

2. THE NATURE OF THE DUNES.

According to Armon (1970), dune-building began on the Spit about 2000 BP, and for most of that time dune formation would have been limited to the western 8km. Only later in the barrier's development, would erosion of sediments from the western end have been likely to produce sufficient sand reserves to permit dune formation along most of the eastern half of the coastline.

The crests of the dunes form a complex, irregular pattern of gently undulating, flat-topped ridges, the highest of which, rising about 8 - 10m above the general surface, occur about 8km east of Taumutu. Dune height decreases steadily farther eastwards, being reduced to about 2m at a distance of 8km from Lake Forsyth.

Although the orientation of the dunes appears at first to be somewhat haphazard, a general pattern is discernible, being most clearly seen from 8 - 14km west of Lake Forsyth, and including the site of the present study (Figs, 3, 4, 5) as described below.

There is a fairly stable coastal dune ridge, about 4 - 5m above m.s.l., equilibrium apparently being maintained between sand-deposition and growth of Desmoschoenus spiralis. The coastal ridge is connected by trailing arms (parallel to the onshore SW wind) to an inland dune ridge, on which sand is almost completely stable, frequently carrying moss and shrubby vegetation. At intervals between these two main lines of dunes, which lie at right angles to the onshore wind, are deflation hollows - flat, roughly circular areas, up to 200m in diameter. These are covered with the smooth, flat pebbles and stones which are typical of the basement material of the Spit.

This kind of dune system is basically of the parabolic type, having apparently been formed by a succession of blow-outs at high points along a coastal dune ridge, the rest of which remained fixed by plants (vide Bagnold, 1941, Landsberg, 1956, Chapman, 1964).

Fig. 4. PLAN OF STUDY AREA (c.f. profiles in Fig. 5)

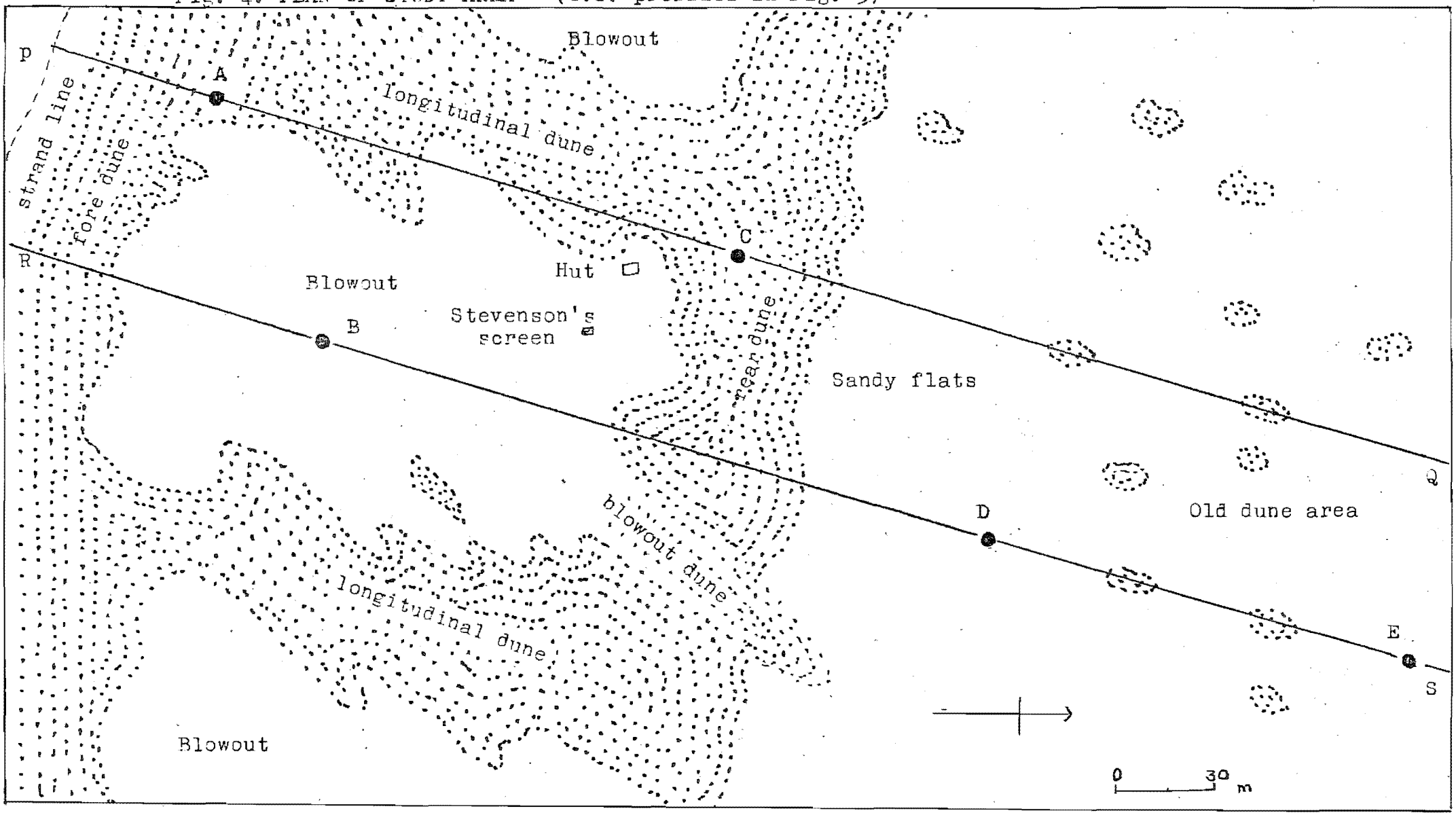
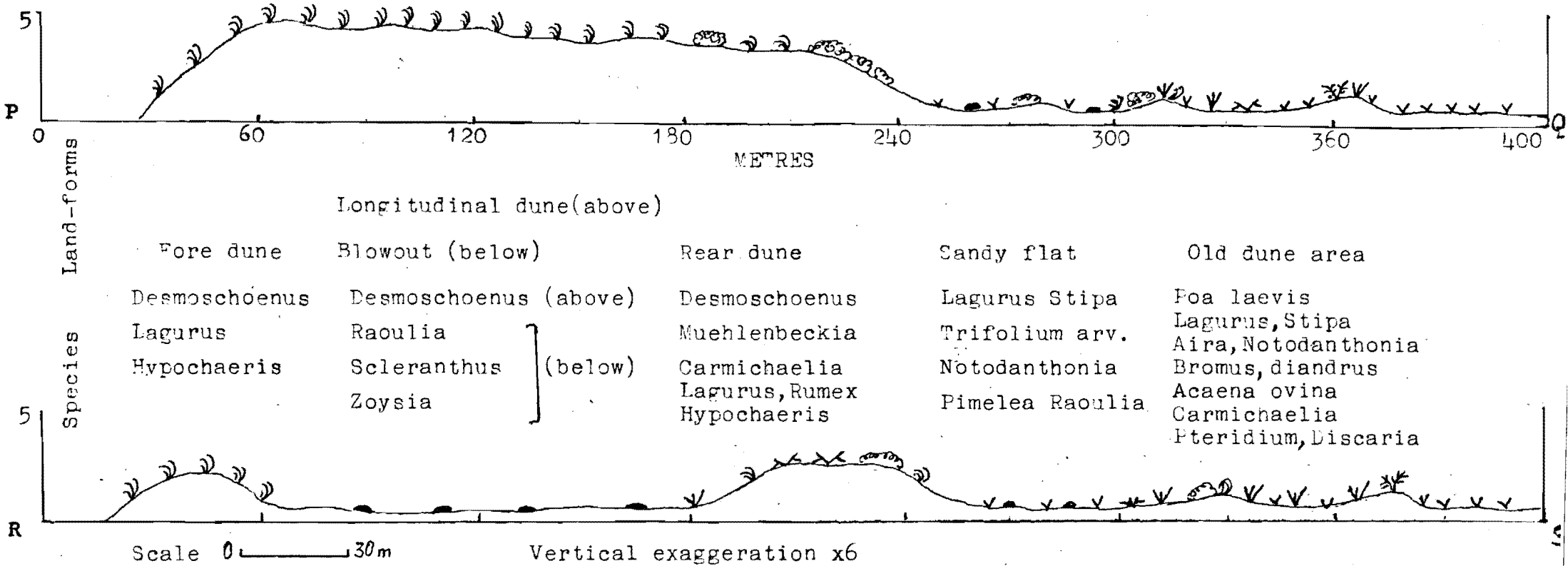


Fig. 5. PROFILE DIAGRAMS ALONG TRANSECTS PQ, RS, OF FIG. 4.



(plants not drawn to scale)

The irregularity of the dune pattern can be partly accounted for by the fact that the dominant influence of the SW wind is modified by strong winds from NE, N and NW. Also, as has been noted by Cockayne (1911) and Esler (1970), irregularity of outline is characteristic of dunes formed by the growth of mounds of sand captured by a plant such as Desmoschoenus, capable of rapid vertical and lateral growth, on a plain where sand is drifting. The gentle slopes and low profiles are partly attributable to the type of vegetation cover, and partly to the coarseness of the sand.

Northward of the main line of inland dunes, running parallel to the shore along the middle of the Spit, is a sandy plain, irregularly dotted with slight undulations, occasionally up to 2m in height. These are presumably the truncated remnants of the earliest dunes formed, before the present seaward dunes cut off the supply of sand from the shore. The surface sand of these dunes is finer, and there is a considerable admixture of dark organic matter and light-coloured silt.

In the western half of the Spit, the above pattern is less clear. There is considerable wave erosion of seaward dune faces, resulting in an increased supply of sand; there is active dune building and dune destruction by wind. Dunes which have been long established, as can be seen from their covering of Muehlenbeckia complexa (pohuehue), are being removed by a combination of wind and wave erosion (Fig. 6) and sand is being blown inland to encroach on the flats (Fig. 7). Nevertheless, the densely-growing pingao, and in one area, marram grass, are still providing stabilising cover on most of the dune crests and slopes, which are protected by fencing from stock. Flat, pebble-covered deflation hollows are much less conspicuous at this end of the spit.

The unusual coarseness of the material of which the dunes are built is a key factor determining their height, form, and general stability. An analysis of beach deposits from a number of representative beaches near Christchurch

Fig. 6. Wave-eroded profile of foredune opposite Bayley's house.

Fig. 7 Active blowout in line of rear dunes opposite Bayley's house.

Fig. 9. Dune and wind stream on rear dunes opposite Bayley's house.

Fig. 11. Sweet Gum in line of rear dunes at study locality.

is illuminating (Knox 1969). A sample from Taumutu beach shows over 60% of the particles $>$ 2mm in size, with less than 5% $<$ 0.6mm; by contrast, samples from Taylor's Mistake and Leithfield show almost all particles to be $<$ 0.6mm, while in a sample from New Brighton all material is finer than 0.3mm.

The dune system is markedly different from that of the Manawatu, described by Esler (1970). The dunes there are built of fine material ($<$ 0.6mm) and are in active movement, although the large-scale planting of marram grass has assited stabilisation since the native dune vegetation was mostly removed by cultural practices by the end of the nineteenth century. The foredunes are 3 - 8m high, the longitudinal dunes higher, and rear dunes up to 12m high, with steep slip-faces which are sparsely vegetated or bare.

An important feature distinguishing the Kaitorete dunes from most other dune systems is the gravel basement, which arrests deflation at a level considerably above the water table (bores on Mr Bayley's property have reached fresh water 5 - 10m below the surface). This accounts for the absence of moist inter-dune slacks, which are characteristic where the whole profile is sand, or the dune is built on impervious rock, and deflation commonly occurs to moist sand just above the water table.

3. RECENT HISTORY AND MANAGEMENT.

The Spit was occupied by Maoris for centuries, until the late 1840's, and much evidence of their activities remains in the form of piles of oven stones at intervals along the area. About 1850, 5000 acres was taken up for farming by W. Birdling (Acland, 1951), and subsequently the whole Spit has been used, mainly as three large run-holdings for sheep plus a few cattle. Hares liberated on Banks Peninsula in 1851, and rabbits in 1887, spread and multiplied on the Spit, and are still abundant. Fires inevitably occurred during the Maori period, and were lit deliberately by the European farmers to burn off scrub and tussock, right until the late 1940's (Mr O.P. Bailey, pers. comm.). Under these pressures, and with the introduction of adventive "weedy" plant species, (such as Stipa variabilis, Lagurus ovatus, Hypochaeris radicata), the indigenous vegetation has undoubtedly changed considerably, especially on the flats, behind the inland line of dunes. On the dunes proper, the indigenous species continue to hold their own, although a few adventive species are common.

There has been little attempt at pasture improvement. During the past two or three years, as a result of using fertilizers and irrigation, crops of lucerne and potatoes have been grown with some success in a small area west of Bayley's house. Some of the dunes opposite this homestead have been planted with marram grass during the past twenty years, to reduce sand movement. Six years ago, the dune area of Bayley's property was fenced off from stock, and several thousand seedlings of Pinus radiata have since been planted, the oldest now being about two to three metres high (Figs. 2, 8).

From 1940 to 1958, according to information from Squadron-Leader Rust, O.C., R.N.Z.A.F. (1970), an area near the junction of Habgood's quarry road and Bayley's road was used by the Air Force as a practice bombing range, but there was little permanent damage to the vegetation, since the small practice bombs exploded above

ground. Circular hollows, about 2m across and 30 to 50cm deep, are still visible. Some fires were started as a result of these activities (Mr A. Birdling, pers. comm.). An area just to the west of Birdling's Flat was also used from 1950 to 1958 for artillery practice, but according to information from Army Headquarters at Burnham (1970), firing was towards the sea, so that only an occasional 3" mortar bomb would have landed on the dunes, making a crater about 60cm wide and 20cm deep.

In the vicinity of Habgood's quarry, the dunes have been considerably affected by heavy machinery, removal of sand, and roading associated with this activity.

Fishermen and picnic parties also frequent the area at the end of the quarry road, and baches have been built at the Birdling's Flat end of the Spit. Apart from this, the main area of the Spit is almost unaffected by human traffic, except for occasional excursions on to the dunes by farmers' landrovers. On rare occasions, unauthorised vehicles have been known to go on to the sand hills.

From the above outline of geomorphology, history and management, it can be expected that, in spite of some inevitable changes wrought by human activity, the plant ecology of the area will, to a large extent, reflect the influence of natural environmental factors.

CHAPTER TWO

CHOICE OF SITE FOR STUDY AND OUTLINE OF PROCEDURE.

After a preliminary survey of a considerable area of the Spit on foot, a locality was selected for detailed study, 9.1km west from the junction of Bayley's road and the Akaroa main highway (vide Fig. 1 and Grid Ref. 204906 N.Z. Topo. Map S93).

This area was selected because it was on a property with the lowest grazing intensity on the Spit, i.e. about 0.24 ewe-equivalents per acre, (Mr A. Birdling, pers. comm.), and provided the greatest variety of indigenous species, in a less disturbed condition than elsewhere; also it was reasonably accessible by car.

The first observations of the study area were made in December, 1970. Throughout 1971, and up to March, 1972, systematic records of climate data were made, at regular four-weekly intervals. Apart from this, twenty-two other visits were made, during 1971 and 1972, to observe and record vegetation changes, soil moisture, and other features. On three occasions the whole of the eastern part of the Spit, from Birdling's Flat to Bayley's homestead, was traversed on foot, to make general notes and photographic records. A low-level flight in a light aircraft was made with Mr McGregor of the Botany Department, University of Canterbury, to obtain a complete series of aerial photographs of the seaward side of the Spit.

At the study locality, field reconnaissance showed that common patterns of vegetation, associated with repeated sets of landform units and habitat conditions, were recognizable. A strip was selected running from the strand line across the Spit in a north-easterly direction, and five stations, A, B, C, D and E were marked with pegs (Figs. 3 and 4). Measurement of climate and soil factors, vegetation analyses and phenological observations were carried out in the vicinity of each of these stations. (See also Ch. 4 for basis of selection of communities).

The areas studied have been designated as follows in all subsequent references:

Station A - fore dune
Station B - blowout
Station C - rear dune
Station D - sandy flat
Station E - old dune area

On the north-west side of the blowout B, a small hut was erected for shelter. Close by, a Stevenson's screen was set up to house a maximum-minimum thermometer; a rain gauge and an anemometer were also installed at this site.

Further details of methods used in the investigations are supplied in Chapters 3 and 4.

CHAPTER THREE

THE ENVIRONMENT

For each of the sections that follow, methods of study, results and observations are given, followed by discussion and some comparison of the conditions likely to be affecting the plant communities at the various microstations.

1. SOILS

At each station, pits 80cm deep were dug, to examine soil profiles. The following descriptions agree closely with those given by Wraight (1957) for similar sites along a transect across the Spit near Bayley's homestead.

(a) Soil Types.

Stations A, B, C. Kairaki Series: soils from dunes and shingle beach, still being deposited.

A. Kairaki sand.
Coarse, grey sand, loose and structureless throughout the profile; roots and rhizomes of Desmoschoenus throughout, plus roots of Lagurus and Hypochaeris down to 40cm; small patches of undecomposed organic matter from Desmochoenus leaves occur at various depths.

B. Kairaki very stony sand.
As above, but with many rounded, flat stones, up to 20cm diameter, especially at the surface, and smaller pebbles scattered throughout the profile, or sometimes in a definite layer between sandy layers; roots of Raoulia occur frequently, penetrating throughout the profile.

C. Kairaki brown sand.
8cm of slightly humus-stained, brown-grey, coarse sand, loose and structureless, densely penetrated by many fine roots, mainly of

grasses. Remainder of the profile coarse, grey sand, as at A, with grass roots continuing down to 40cm; Muehlenbeckia, Desmoschoenus, and Carmichaelia roots throughout.

Stations D and E. Waikuku Series: from wind-blown sand and loess, deposited on top of stony Taumutu soils.

D. Waikuku brown loamy sand-brown stony sand.
15cm grey-brown loamy sand, structureless, but held together by a mass of fine roots of grasses and forbs; some pebbles at the surface.
12cm brown loamy sand with many pebbles up to 2cm; roots still abundant. Remainder of the profile very stony brown sand, with a few roots of Raoulia.

E. Waikuku grey loamy sand, bordering on Taumutu fine loamy gravel.
15cm dark grey sandy loam, structureless but held together somewhat by a mass of fine roots of grasses and forbs. 15cm grey-brown loamy sand, with many stones up to 2mm; roots of Poa laevis abundant. Remainder of the profile grey-brown loamy sand and gravel, stones increasing in size up to 6cm, roots of Carmichaelia present throughout.

Photographs of profiles were not taken, since they were provided by Wraight (1957), who dealt with soil types in more detail than is given here.

Discussion:

The main points to be noted are the abundance of stones in the profiles at stations B, D, and E, and the fact that even the oldest of the dune soils at D and E (which have presumably been developing for several hundred years) are very poorly developed, with horizons barely distinguishable. By comparison, dune soils of similar age in higher rainfall regions of England and North America have developed to much greater maturity (vide Salisbury, 1952, Wilson, 1960, Olson, 1958a).

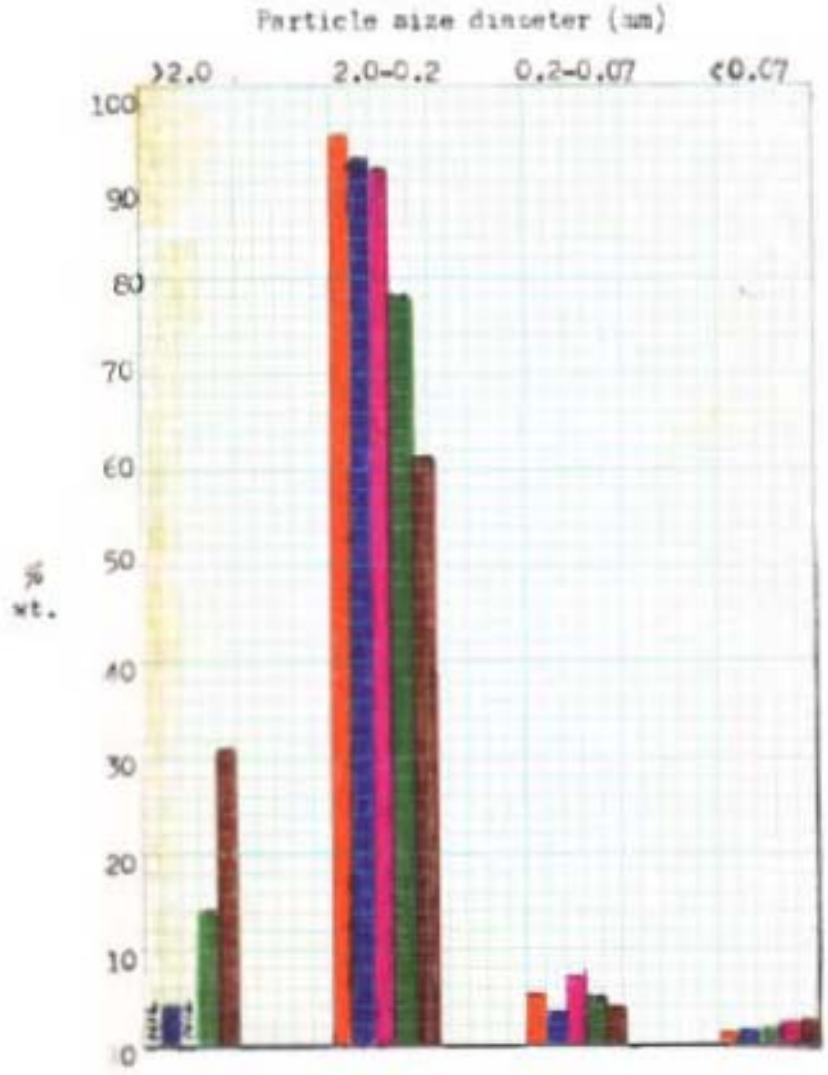


Fig.9. Particle size analysis of dune soils at microstations, each percentage calculated from sum of three samples, ie.from 0-10, 20-30 and 40-50 cm depths. (note stones)1.75 cm diameter excluded)
Station A —— ,B —— ,C —— ,D —— ,E —— .

(b) SOIL TEXTURE AND ORGANIC MATTER.

For each station, particle size analysis was carried out on a pair of 125ml samples from each of the three levels used in soil moisture sampling, as described in (c) below. These samples, from which stones larger than 1.75cm were excluded, were dry sieved to separate the material into 4 fractions. Results are given in Appendix I, Table 1, and Fig. 9. No attempt was made to determine any clay fraction, which was negligible in all cases.

Organic matter, as determined by Wraight (1957) is indicated in Appendix I, Table 2a; 2b gives some values obtained by Botany Honours Part III students. No further measurements were made, but since the presence of organic matter was considered likely to affect surface wetting and water movement through soil profiles, some relevant field observations were recorded.

In general, the climatic conditions and spareseness of the vegetation are not conducive to humus formation, except to a slight extent in the old dune area. At all other sites the small amount of surface litter produced by the plants is rapidly dried and blown away. However, when subterranean plant organs die they leave patches of organic matter which may resist decomposition for a long time. The most notable example of this is provided by Desmoschoenus; old dead rhizomes occur frequently throughout the dunes, and their densely packed leaves, protected by their impervious waxy cuticle, are particularly resistant to decay. Pockets of this material, resistant to wetting, were frequently met while sampling the profiles at A and C. Similar patches of incompletely decayed organic matter derived from Raoulia were sometimes encountered in the top 15cm of the profile at D.

At E, because of the denser vegetation and some protection from wind, litter accumulates to a slightly greater extent. However, humus formation is probably restricted by the sparseness of the soil population of invertebrates and saprophytes all of which are dependent on adequate moisture. To the naked eye, fungal mycelia were

obvious in the litter only for a brief period in spring; a few Agarics emerged at the surface in June and again in September (one even in the blowout area). Earthworms were conspicuously absent from all soil pits that were dug (although one was found under a patch of cow faeces). Beneath mats of dead tussock and Desmoschoenus leaves in spring were found Thysanura in fairly large numbers, a few isopods (Porcellio scaber), and occasional larvae of various carabid and scarabaeid beetles, and of tipulid flies. Smaller organisms would no doubt have been revealed by more intensive searching.

* In dunes nearer the sea, and associated with Desmoschoenus, the larvae of the sandsscarab (Pericoptus truncatus) and its adult form were common, while in the blowout area colonies of ants were occasionally found under large stones. No other soil invertebrates were noticed at A, B, C, or D.

Discussion:

The unusual coarseness of the sand, and the amount of gravel present, can be judged from Appendix I, Table 1, and Fig. 9 (remembering that stones 1.75cm were discarded from the samples at stations B, D and E). Comparison with other coastal sands is made in Ch. 1.

The particle size distribution of sand from dunes at A and C shows slightly finer material at C, which is predictable from the normal winnowing effect of the wind. The profile at A shows great uniformity at all depths measured; but at C some stratification is noticeable, and the unpredictable changes in grades of sand at different depths is likely to affect penetration of moisture at this station. Similar stratification is noticeable at station B, which is also distinctly different from the dunes on account of the presence of pebbles and quite large stones at all depths. At D there are fewer large stones than at B, but a greater proportion of>2mm material, fairly evenly distributed throughout the profile, and there is a slight increase in the amount of silt. At E the amount of>2mm material is double that at D, although noticeably less in

the top 10cm of the profile, where fine wind-blown loess is augmented by organic matter.

The overall poverty of the soil population, together with the high lignin content of much of the plant material, results in litter accumulating at the surface, where it is likely to reduce infiltration of rain into the soil. On the other hand, humus which has become incorporated into the top 15cm or so of the soil, as at E, can be expected to increase the WHC of this soil.

(c) SOIL MOISTURE.

Water-holding capacities of the soils, as determined by Wraight (1957), calculated on < 2mm material from samples at 20cm depth, are shown in Appendix I, Table 2a. No further determinations of WHC were made in the present study.

Such figures for WHC give little indication of the water actually available to plant roots (which in this habitat frequently extend to a depth of a metre or more), nor do they allow appreciation of how much the water availability may vary at different times of the year. To obtain information on these aspects, soil sampling at a number of levels was carried out on 19 occasions, between 7 March 1971 and 3 August 1972, covering all seasons, and especially concentrating on periods of drought and periods of heavy rain, at all five stations.

The method of sampling involved digging a pit about 30cm square (though necessarily larger in very dry periods, when loose sand was a problem falling into the hole). As the desired level was exposed, a clear plastic beaker of 125ml capacity was used to scrape right round the circumference of the pit, thus obtaining a more representative sample than if taken from one side only. The transparency of the container enabled checking when it was full without air gaps, and the loose but heavy nature of the material enabled it to assume its normal bulk density when the container was jarred slightly. Stones larger than 1.75cm diameter were deliberately excluded. The sample was levelled off at the top and transferred to a labelled tin with a tight-fitting lid. All tins were transported in closed plastic bags and weighed within 24 hours. The samples were then oven-dried in the same (open) tins, for 8 hours at 100°C (this having been found sufficient to ensure steady weight), and then reweighed. As some rusting of the tins occurred after 6 months, their weights were rechecked, but no significant changed had occurred.

Initially, at each station a single sample was taken at each of 5 depths, namely 0-10cm, 10-20cm, 20-30cm,

30-40cm and 40-50cm, but differences of water-content were too small to justify this, so samples were then restricted to 3 depths, i.e. 0-10cm, 20-30cm and 40-50cm.

Samples were duplicated by digging two pits at each station, spaced about 2m apart, on areas of similar microtopography and surface cover, as indicated in the table of results, except that for station E, on some occasions, one set of samples was taken from under dense moss cover, and the other under a relatively bare surface with no moss, as moisture here was found to contrast strongly.

In discussing the measurement of soil water content, Slatyer (1967) states: "Because of variations in the soil, more than 10 replicates are required to show that differences of 1% between occasions are significant". The desirability of taking more replicate samples in this case was recognized, but was precluded by logistic and time considerations. Since the greatest variations of soil and of water content in a single profile occurred at D and E (to a lesser extent at C), these stations were sampled in quadruplicate on two occasions, in June and August, 1972 (Appendix I , Table 3b). However, it became clear that it was virtually impossible to find two comparable profiles at any of these stations, because of the variability of stony layers, and the unpredictable presence at different depths of undecomposed buried litter (as described under Soil Texture). These factors naturally affected the depth of wetting front.

Various authors have commented on the difficulties of calculating water content in gravelly soils, in which figure for % water content based on mass will be lower than corresponding values for soils of finer nature (Gardner, 1960). Salisbury (1952) recommends basing calculations on % volume, since it is the volume, not the mass, of soil exploited by roots, which is biologically significant.

In this case the more usual convention has been followed of expressing water content as % based on mass:

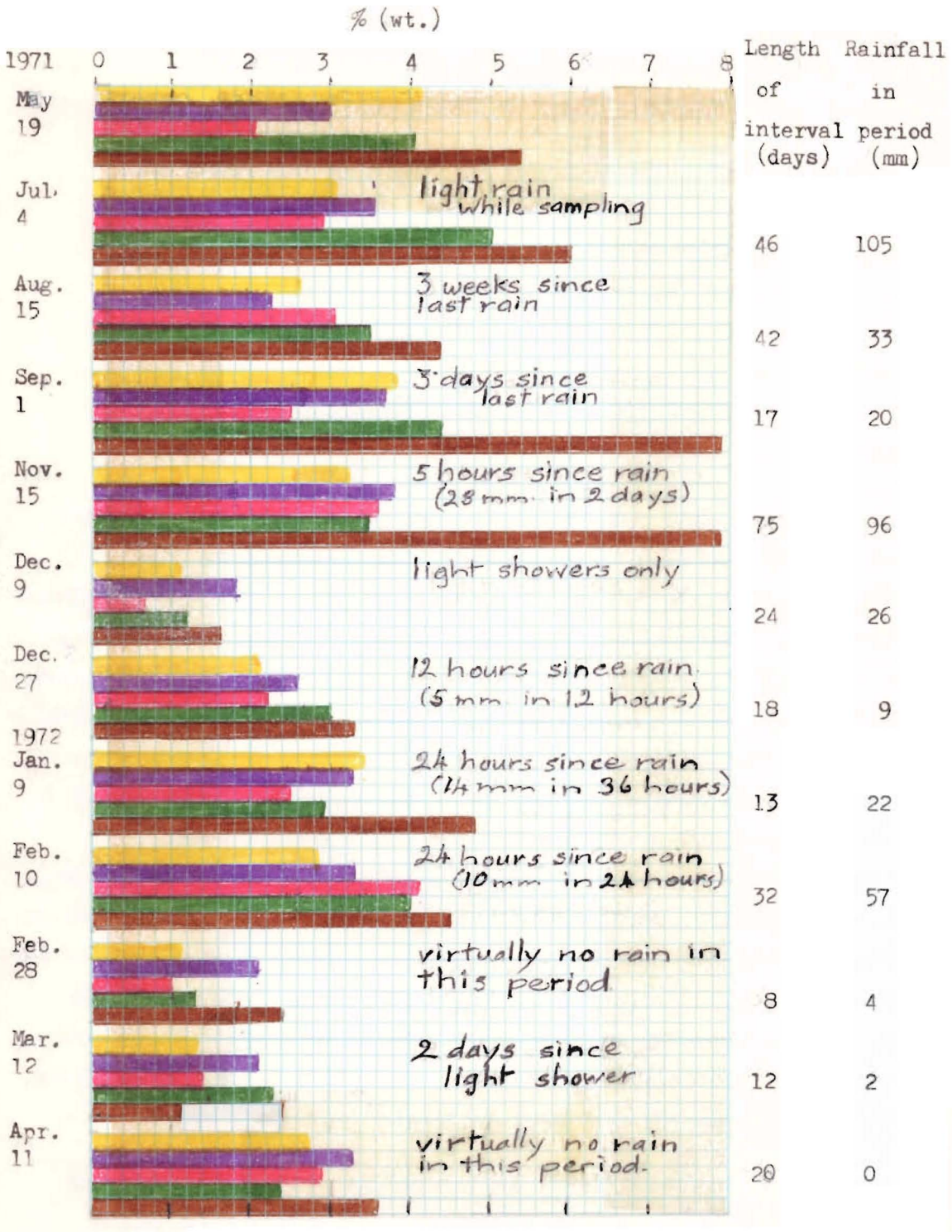


Fig. 10 Soil moisture content, % by weight, at five microstations May 1971- April 1972.

Each percentage calculated from sum of threesamples, at depths of 0-10 cm, 20-30 cm, and 40-50 cm.

Station A —— , B —— , C —— , D —— E ——.

Table 1. Infiltration and percolation of water at microstations.

(a) Sampled 15 Nov.1971, 5 hours after cessation of continuous rain for 36 hours (28.4 mm).

Soil moisture % wt.

Depth cm	Stn A		Stn B		Stn C		Stn D		Stn E	
	i	ii	i	ii	i	ii	i	ii	i	ii
0-10	1.6	1.8	2.1	2.7	1.3	1.3	1.2	4.1	12.0	8.5
20-30	3.8	3.9	3.7	4.9	6.1	6.1	4.4	6.0	8.5	7.8
40-50	4.1	4.2	4.8	4.7	5.7	5.7	1.5	3.9	3.1	3.7
Total	9.5	9.9	10.6	12.3	13.1	12.8	7.1	14.0	23.6	19.0

(b) Sampled 10 Feb.1972, 24 hours after cessation of continuous rain for 12 hours (10.4 mm).

Depth cm	Stn A		Stn B		Stn C		Stn D		Stn E	
	i	ii	i	ii	i	ii	i	ii	i	ii
0-10	0.6	1.0	2.2	2.5	1.0	3.2	2.9	4.2	1.9	5.0
20-30	3.2	4.0	3.4	4.6	6.3	5.2	5.2	4.6	6.3	1.2
40-50	3.5	4.5	2.9	3.9	4.9	4.1	3.7	3.6	5.3	1.5
Total	7.3	9.5	8.5	11.0	12.2	12.5	11.8	12.4	13.5	7.5

(c) Sampled 9 Dec.1971, after three weeks without rain rain.

Depth cm	Stn A		Stn B		Stn C		Stn D		Stn E	
	i	ii	i	ii	i	ii	i	ii	i	ii
0-10	0.0	0.4	0.5	0.4	0.0	0.0	0.7	0.1	1.3	1.3
20-30	0.5	1.3	2.6	1.6	0.7	1.0	1.4	1.7	2.4	1.8
40-50	1.5	2.1	3.1	2.7	1.2	1.0	1.5	2.0	1.2	1.8
Total	2.0	4.3	6.2	4.7	1.9	2.0	3.6	2.7	4.9	4.9

NOTE: Duplicate samples i and ii at each station taken from beneath bare surfaces, except for " ii where surface was moss-covered.

$$\frac{W' - W''}{W''} \times \frac{100}{1}$$

W' = original weight of soil sample in g.
W" = weight of soil sample after drying. (It is assumed that volumes are near constant.)
Bulk density figures are given also, to indicate texture.
Results are summarised in Appendix I Table 3a, and Fig.10.

If the total soil moisture for each profile is considered, the values are likely to give a fair indication of soil moisture available at different sites.

It was considered that the variable rates of water movement through profiles at different sites was likely to be a significant factor in determining plant survival. Glover et al (1962) investigated this problem in dry grassland vegetation in East Africa, by means of digging trenches and measuring the depth of the wetting front after rain. This method was not practical for the present study, partly because of the sandy soil and partly because it would have involved too much time and labour. However, soil sampling was done on a number of occasions when rain fell after a prolonged period of drought, and some of these results, shown in Table 1, enable comparison of infiltration and percolation at different sites.

Interception of rainfall by vegetation is well known to be an important factor affecting soil moisture in dry climates. Glover (1962) noted the significant reduction of infiltration under shrubs compared with tall grasses. In the present study, sampling was deliberately not carried out beneath shrubs or tussocks; but it must be recognized that interception of light rainfall would be considerable in the case of Muehlenbeckia on the rear dunes and Carmichaelia-tussock cover in the old dune area.

The significance of the mossy cover, prevalent over much of the old dune area, was investigated, since the moss was observed to hold water like a sponge. On 7

occasions the two profiles sampled at E were chosen so that one was under a bare sandy surface and the other was under a dense closed cover of the moss Triquetrella papillata. The results (Table 1b) almost invariably show that the total amount of water in the moss-covered profile is less, and tends to be concentrated in the top 10cm (where spongy organic matter from dead moss was noticeable). To check the water-holding capacity of moss, a sample was taken from an area of ground 30cm square during a very dry period and weighed; it was then sprinkled with water until it was saturated and after dripping ceased it was re-weighed. It was found that 56.7g of moss absorbed 283.7g of water (i.e. 5 times its own weight). Since the moss quickly loses this water in the windy, dry conditions which prevail for most of the year, it is obvious that occasional showers, even if fairly heavy, are unlikely to penetrate the soil which is moss-covered.

Movement of water by capillarity is not likely to be a very significant factor in the coarse-textured soils of the Spit. The capillary fringe would not extend for more than 60cm above the water table (Slatyer, 1967), and as this is 5-10m below the general surface of the Spit, this source of water could be utilised only by the deepest-rooted species, e.g. possibly Carmichaelia.

Water vapour movements into and through the soil are likely to have important effects, especially in the driest periods. A discussion of this is deferred to the sub-section on temperature and humidity dealt with under Section 3 of this Chapter.

Discussion:

It would appear that approximate field capacities of the soils (i.e. of whole profiles to 50cm depth) are likely to be represented by values shown for November 15, in Fig. 10. At this time there had been sufficient rain to ensure complete wetting throughout all profiles, and owing to the rapid drainage, FC would probably be reached within a few hours of cessation of rain, when these samples were taken.

A - 3.4%
B - 3.8%
C - 3.6%
D - 3.5%
E - 7.9%

The reason for these very low field capacities is revealed by reference to Fig. 9 which shows the very small proportion of fine material throughout. In D the increased water-holding capacity of the fine material near the surface appears to be negated by the low water-holding capacity of the stony lower layers. Although E has an even higher proportion of stones at the lower levels, the presence of a certain amount of humus in the upper level is responsible for an overall increase in FC. Probably the FC figure of 3.8% for B is too high; comparing the texture of this site with that of the fore and rear dunes one would expect it to be more like 3.2%. In view of the fact that B, D and E moisture determinations were made on samples from which a few large stones were discarded, the actual % volume of water available here is likely to be slightly less than the figures indicate. Because of the lack of fine particles of colloidal nature (except for the small amount of humus at E) hygroscopic forces will be negligible.

The pattern revealed by Fig. 10 is discussed below, but conclusions can only be regarded as tentative in view of the limitations of the data.

The least variation in moisture content through the year is shown in the blowout area (from 1.8% in extreme dry to 3.8% in extreme wet conditions). In the driest period (9 December) this site retains more moisture than any other, in spite of evaporation data indicating the highest evaporation rate here (Fig. 31). This might be explained by the proximity of the water table, reducing seepage (c.f. the dune slack region of other dune systems) but this seems improbable since the water table is likely to be more than 5m below the surface (from evidence of bores further across the Spit, see Ch.1). More likely it is due to the absence of interception and run-off (both of which

are factors on the dunes), unimpeded percolation, and the lack of plants to remove water by transpiration.

After adequate rainfall, (e.g. August, November and February 10) the water content of the rear dunes is somewhat higher than that of the foredunes, probably because of a slight increase in the proportion of fine particles in the former. The lower % of water at C in low rainfall periods is probably due to fine-textured material at the surface resisting infiltration and/or the slightly higher evaporation rate shown at this site.

In general the sandy flat has soil moisture at least equal to, and usually higher than, that of the dunes. This can be related to the higher proportion of silt and/or to lack of run-off. The fact that in January D has less moisture than A, and in April less than both A and C, is probably explained by higher transpirational losses from the cover of relatively shallow-rooted grasses and Trifolium arvense. Willis et al (1959) comment on the low moisture content of dune pasture (1.7%), compared with dunes (4.9%), in a very dry season, attributing this to the presence of moss and a dense grass root zone within 30cm of the surface.

The old dune area always has more moisture than any other site, except in the two driest periods when it would seem that the density of vegetation must account for high losses by transpiration. The higher WHC has already been referred to.

On several points the findings are in contrast to those of other writers describing dune systems in which there was relatively little textural stratification in the profiles, and considerably smaller grain size. Oosting (1945) sampled soil at 5 stations from fore dunes to rear dunes (including a dune slack) and found no significant difference in water availability - presumablythe rainfall in North Carolina in mid-summer was sufficient to wet all sites evenly.

Wraight's figures for WHC of the Kaitorete dune soils (Appendix I, Table 2a) show an increasing gradient from 22% on the fore dune to 38% on the sandy flat (corresponding to D)

and 48% on the equivalent of my old dune area as at E. These last two figures, as he points out, are likely to be far too high, having been obtained from samples of < 2mm material.

Salisbury (1952) suggests that the water content of old dune soils is likely to be about twice that of young dune soils, when at field capacity.

In a study of soil moisture in a dune profile during a drought, Salisbury (1952) reported a steadily increasing gradient from 0.63% at 3" (7.5cm) depth to 5.1% at 48" (120cm) depth. Such figures would appear to be typical of a sandy profile with no barriers to percolation. In the soils of Kaitorete Spit, (-Table 2c) samples show in the dry periods measured on December 9, February 28 and March 12, an increasing downward gradient of moisture at all stations except E, where most moisture is found in the 20-30cm level (held by the fine material).

At other measuring times the results are complicated by numerous factors, such as the amount of rainfall over the previous week or two, and the degree of infiltration (influenced by surface slope, texture and cover), as well as the conditions of temperature, wind and humidity that have prevailed.

The multiple irregularities of pattern shown in Appendix I, Table 3 are, therefore, difficult to summarize and more work is needed.

The figures in Table 1a and 1b indicate that the rapid percolation one would expect in such coarse-textured material is frequently impeded somewhere about the middle of the profile, especially at C, D and E.

(d) SOIL NUTRIENTS AND SOIL REACTION.

Some of the results obtained by Wraight (1957) are shown in Appendix I, Table 2a; in 2b are some values obtained by Botany Honours Part III students at Canterbury University.

Time did not permit further investigations in the present study.

Discussion:

From values in Appendix I, Table 2a and 2b, one can discern gradients across the Spit from A to E, summarized below:

	Fore dunes		Old dunes
C%	very low	-	low
N%	very low	-	low
$C/_N$	medium	-	high
Pme%	medium	-	medium (slight increase)
CEC	very low	-	medium
TEB	very low	-	medium
BS	very low	-	medium
Ca me%	very low	-	medium
Mg me%	low	-	medium
K me%	medium	-	very high
pH	very sl.acid	-	moderately acid

There are no figures available for sodium chloride content of these dunes, but in other studies the amount has generally been found insufficient to have any chemical or osmotic effects (Oosting, 1942).

Although the chemical aspects of the Kaitorete soils undoubtedly require more intensive study, it is possible to comment on certain features which are in marked contrast to dune soils studied in other areas, where more favourable climatic and edaphic conditions prevail. Considering that the Kaitorete dune system is estimated to have been in existence for at least 500 years, the values tabulated above indicate unusually slow soil development, correlated with the very low water availability.

By contrast, dune soils 280 years old, at Blakeney Point, Forfolk, are described by Salisbury (1925) as having 15% C content (three times that found in the oldest dunes at Kaitorete), while Wilson (1960) gives a value of 12.6% C for 200 year old dunes at Dorset; (in the latter, very rapid accumulation of organic matter and lowering of pH was attributed to early invasion by Calluna). Salisbury (as above) noted increasingly rapid augmentation of organic matter after 200 years. In most of the English dune studies the young dunes have been characterised by high initial calcium carbonate content (notably lacking at Kaitorete) and moderately high pH, which is not the case at Kaitorete.

Wright (1956) has commented on the influence of grain size on the nutrient content of dune soils in Morayshire. When soil samples were separated into 5 size fractions, from 0.5 to 0.1mm, no significant differences appeared in the available Mg, K and Na, but for the total available P three or four times as much appeared in the smallest size fraction compared with the largest. The small proportion of fine material in the Spit dunes may, therefore, be a factor contributing to P deficiency.

2. SAND MOVEMENT.

Although the dunes in the eastern half of the Spit are relatively stable, compared with those in the western half, there was some sand movement noticeable at the study locality, especially during strong south-west winds. On such occasions, in the vicinity of Station B, sand particles could be felt to sting the legs. The abrasive effect of such particles was indicated by the fact that the aluminium plate of the thermometer fixed vertically at 30cm, facing south, at this station, became so severely pitted after a year that the engraved figures were barely legible.

To get an approximate idea of the extent of sand movement, two wooden stakes were fixed vertically on the unvegetated blowout dune (Fig. 11) - one at the toe of the north-east slope, and one farther to the south-west, and the sand level marked. Between March, 1971 and March, 1972 there was negligible deposition or removal of sand at these stakes.

On 10 December, 1971, sand traps were installed at Stations A, B, C and D, in the form of small tins of depth 3cm, diamet er 6cm, and volume 100ml. These were buried with their tops just level with the surface, two tins close to each marker stake. At stations A, B and C, three aerial traps were also installed. These were constructed after the model described by Butterfield (1971). The collecting device used was a T-shaped P.V.C. plastic pipe-connection, of 7cm diameter; one aperture was covered with fine gauze (substituting nylon for the stainless steel 120 mesh of 212 micron aperture used by Butterfield). Particles of sand blown into the open arm of the T dropped vertically down the upright member into an attached glass jar of 140ml capacity. Each instrument was wired firmly between two stakes, facing south-west, with the lower lip of the intake 8cm above ground level, and the jar partly buried in the sand. No aerial trap was used at D, where sand movement is very slight; E was excluded altogether for the same reason.

Replication of traps, including some facing in other directions, was obviously desirable, but not practicable,

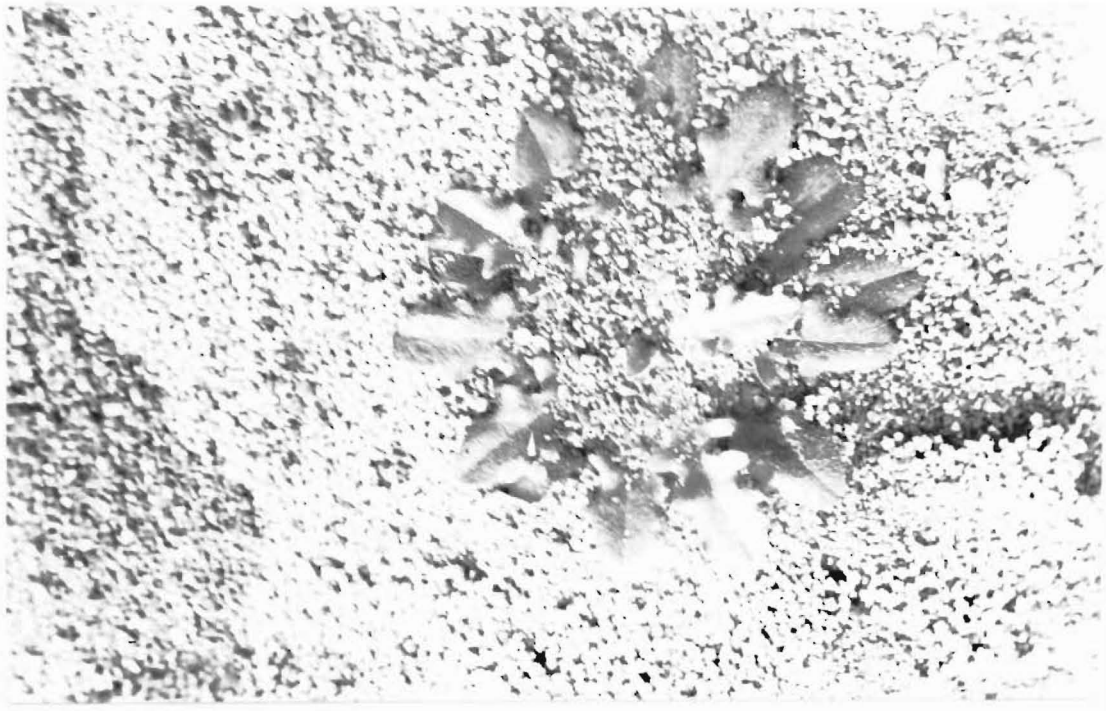


Fig. 14. Blown sand deposited on Hypochaeris radicata,on blowout. Note burial from wind from left (westerly).

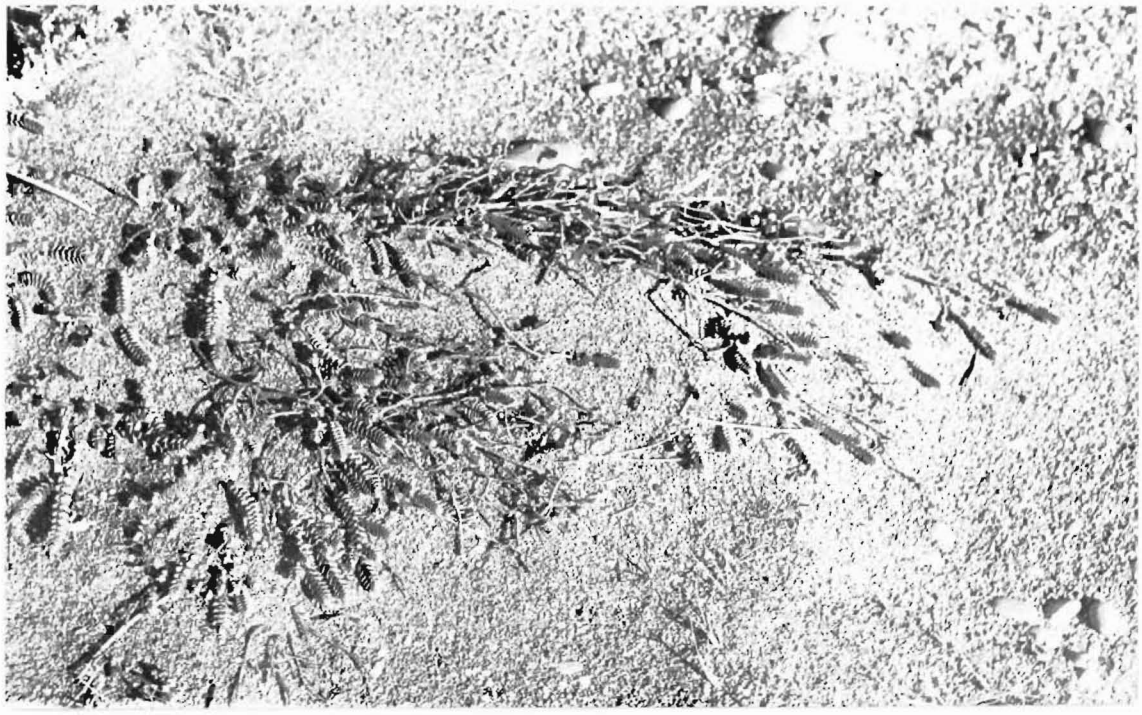


Fig. 15. Blown sand deposited on Plantago procumbens,on blowout.

in view of the time needed for other studies. Results are, therefore, inadequate, but indicative of the scale of sand movement.

Volumes of sand collected were measured on 10 February, 10 May and 10 June 1972. Shortly after this, two instruments were found overturned by cattle, or possibly by vandals, and the investigation was terminated.

Results are given in Appendix I, Table 4a; Table 4b gives an analysis of particle-size of the sand moved (i) at surface level, for 4 stations; and (ii) at 8-15cm level for station C (other samples were lost when the instruments were interfered with).

Some observations on sand movement in relation to the plants are relevant here. Figs. 12 and 13 show plants of Hypochaeris radicata, with a light covering of sand (note coarseness of particles), and of Pimelea prostrata covered by sand about 3cm deep, after two days of strong SW wind. It was noticeable that much of this sand was subsequently dispersed by light winds from other directions. Some of the larger dune shrubs such as Muehlenbeckia and Dodonea bear evidence of their lower portions being buried under about a metre of sand (Fig. 59); further reference is made to this in Ch. 4.

It was frequently observed that young seedlings, and even plants at least a year old, of Raoulia, Scleranthus and Craspedia growing on the blowout, were killed as a result of sand burial or the scouring of sand away from their roots.

It is well known that Desmoschoenus, like Ammophila, thrives best where steady sand accretion occurs. The reason for this, and some of the effects of sand abrasion and salt spray on plant forms, are discussed in Ch. 4.

Discussion:

From the small amount of data available (Appendix I, Table 4a), only very general statements can be made.

Predictably, the amount of sand movement follows a

decreasing gradient from A to D. The amount of sand moved at the surface of the fore dune appears to be about twice that moved at the surface of the blowout, which in turn is slightly more than at the surface of the rear dune.

The mobility of the sand is very low in comparison with most dune systems, which are usually built of much finer material. Esler (1970), describing the Manawatu dunes, noted sand transported inland over a distance of two miles (3.2km), whereas at the Spit there is no appreciable sand movement beyond the main line of rear dunes, which are about 250m from the shore.

Some of the material moved at the surface is surprisingly coarse (Appendix I, Table 4b). At B the greatest proportion of the material collected was >1mm (many pebbles being up to 5mm), and was moved mainly by rolling. Finer material was moved by saltation, at heights varying from just above the surface to about 60cm, depending on grain size and wind velocity. Analysis of the sample from the sand trap indicates that grains carried at a height of 8-15cm were between 0.6 and 0.2mm in size.

The stability of the dunes is largely attributable to the coarseness of their constituent material, but there are other contributing factors. The predominant onshore winds, being from the south and south-west, are frequently accompanied by rain, reducing the mobility of the sand, while the drier prevailing winds blow from an opposing direction (north and north-east). In addition, reasonably good stabilising cover is provided by the indigenous vegetation on the fore and rear dunes. Whereas the rear dunes of the Spit are never more than 4-5m high and have leeward slopes at a very low angle, the much greater degree of sand mobility in the Manawatu dune system has resulted in much higher rear dunes (up to 12m), with a steep slip-face on the lee side.

A most distinctive feature of sand movement at the Spit is the fact that the inter-dune flat areas have been formed by deflation down to the gravel basement, and not to a water table, as is characteristic of most dune systems.

Consequently, there is no equivalent of the usual wet dune slack areas, with their characteristic flora (cf. Esler, 1970).

Some other information relevant to sand movement is contained in the sub-section on wind, in Section 3 of this Chapter.

3. CLIMATE *

(a) TEMPERATURE AND HUMIDITY

One maximum-minimum thermometer was installed in a Stevenson's screen, which was set up 1.5m above ground level, at the northern end of the blow-out area marked Station B.

Maximum-minimum thermometers were installed at three different levels, at each of stations A, B, C, D and E as follows:

(i) 30cm above ground level, attached vertically to a 10cm-wide, white-painted board, which was firmly wired to the south side of an iron standard in such a way as to minimise the likelihood of shaking by wind or passing animals, and to shelter it from direct solar radiation. Comparison with a thermometer facing north on a sunny day showed that the temperature registered was 1°C lower when the thermometer was shaded in this way.

(ii) At ground level, placed horizontally on the surface (in its natural vegetated or bare state), protected from trampling, and shaded from direct solar radiation, by a small tent-shaped, white-painted wooden shelter, open at both ends. Comparison with an unshaded thermometer in this position on a sunny day showed about 0.5°C lower on the shaded instrument. Geiger (1950) points out that a thermometer on the ground is not measuring surface temperature, but the temperature of the air layer immediately above the surface.

---

* Note that the nearest meteorological station to Kaitorete Spit is at Lincoln College, about 20km inland to the north (Fig. 1). For comparative reference, climatic records from Lincoln and also from Christchurch are included in Appendix II.

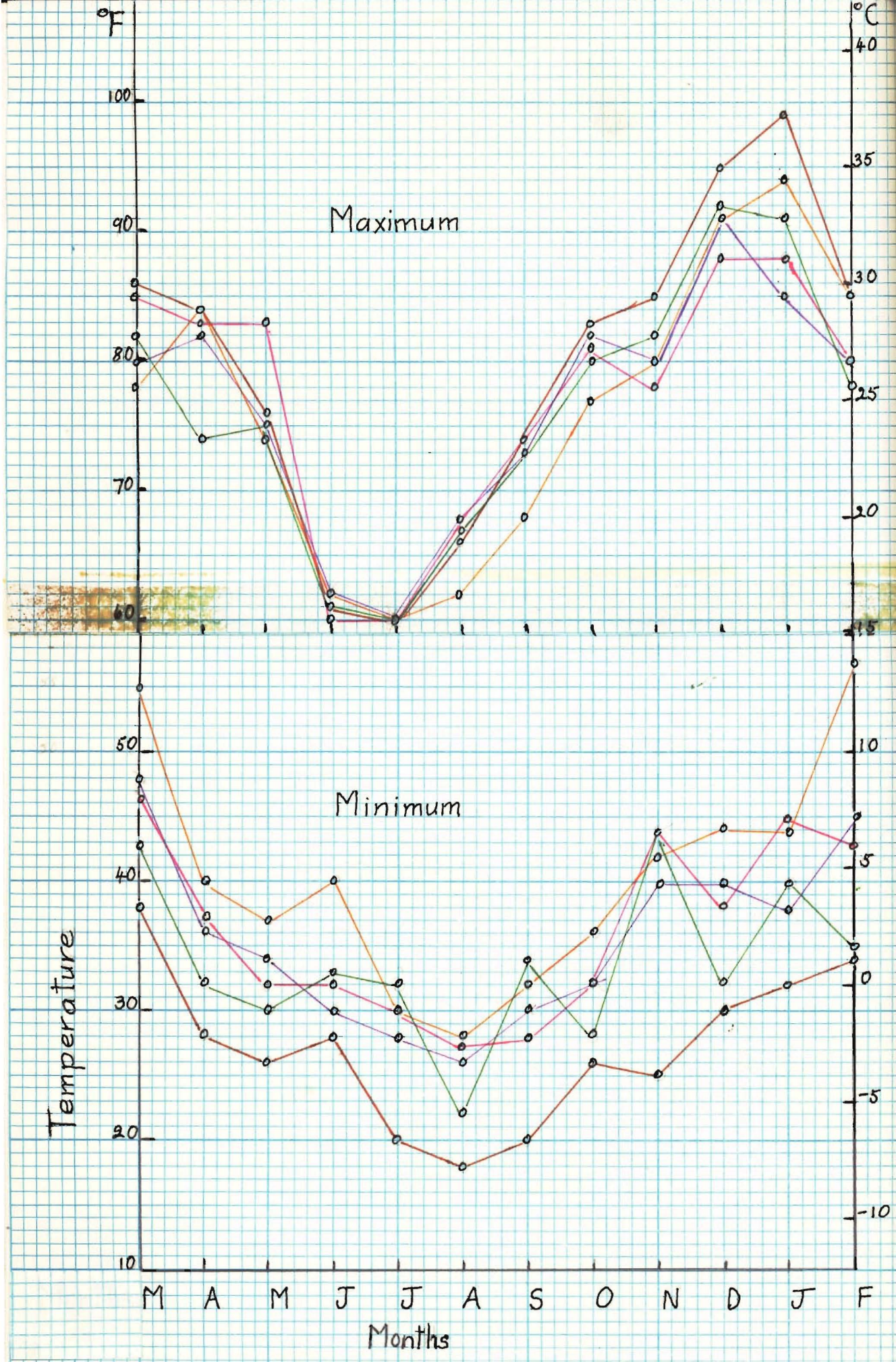


Fig.14. Comparison of air temperatures at five stations March 1971-Feb 1972

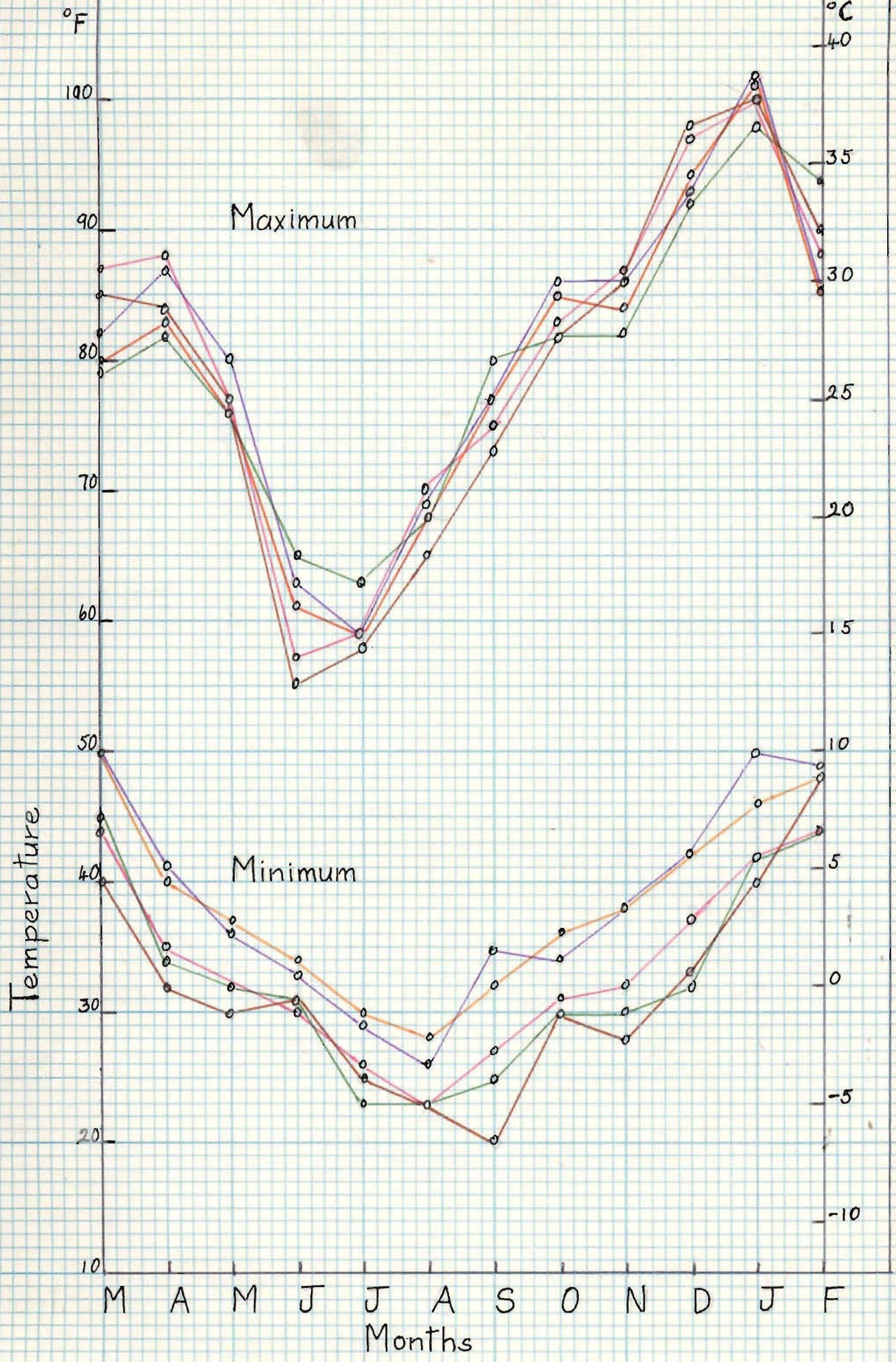


Fig.15. Comparison of surface temperatures at five stations. March 1971 - Feb 1972

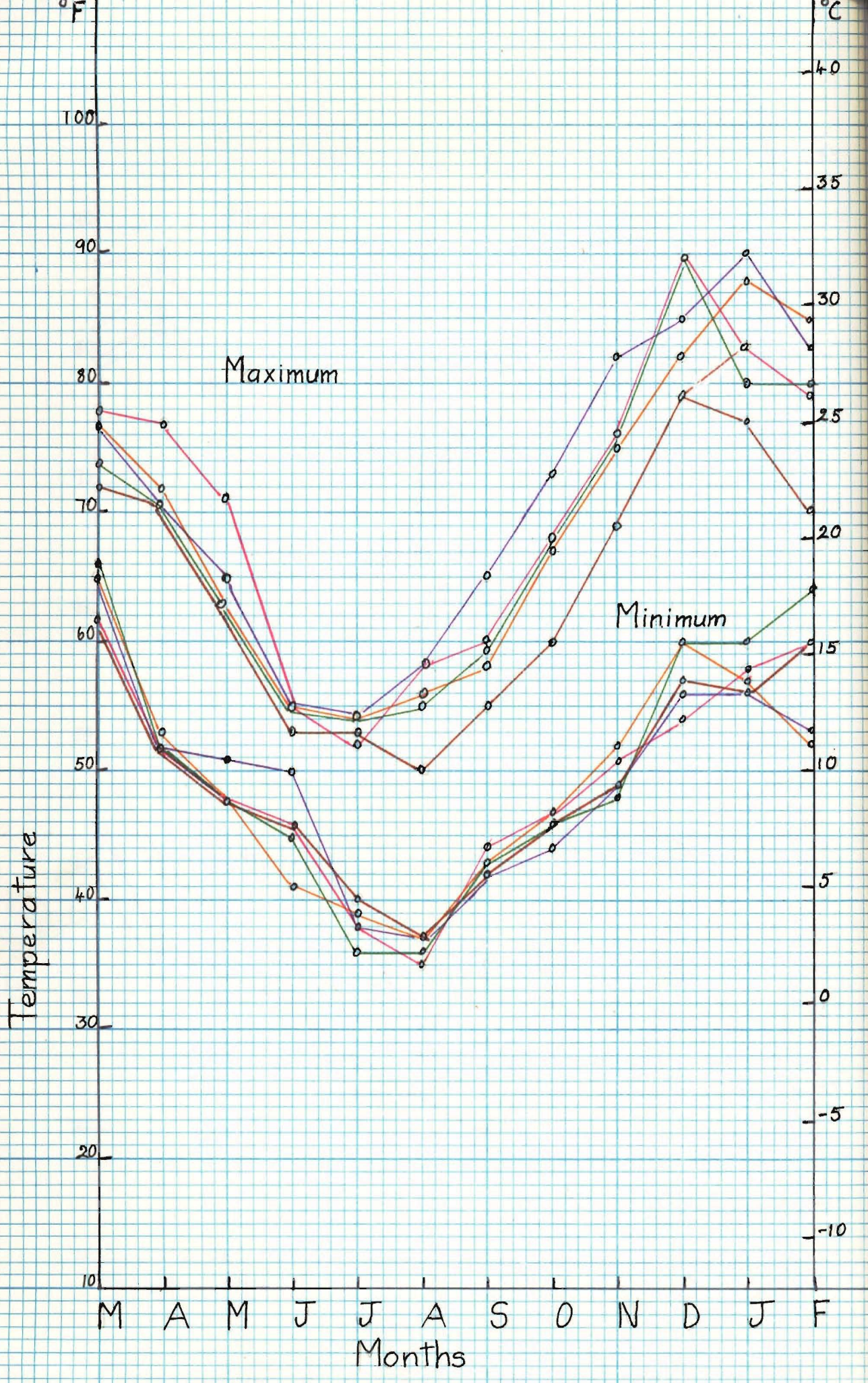


Fig.16. Comparison of soil temperatures, 10 cm. depth, at five stations, March 1971 – Feb. 1972.

—A —B —C —D —E

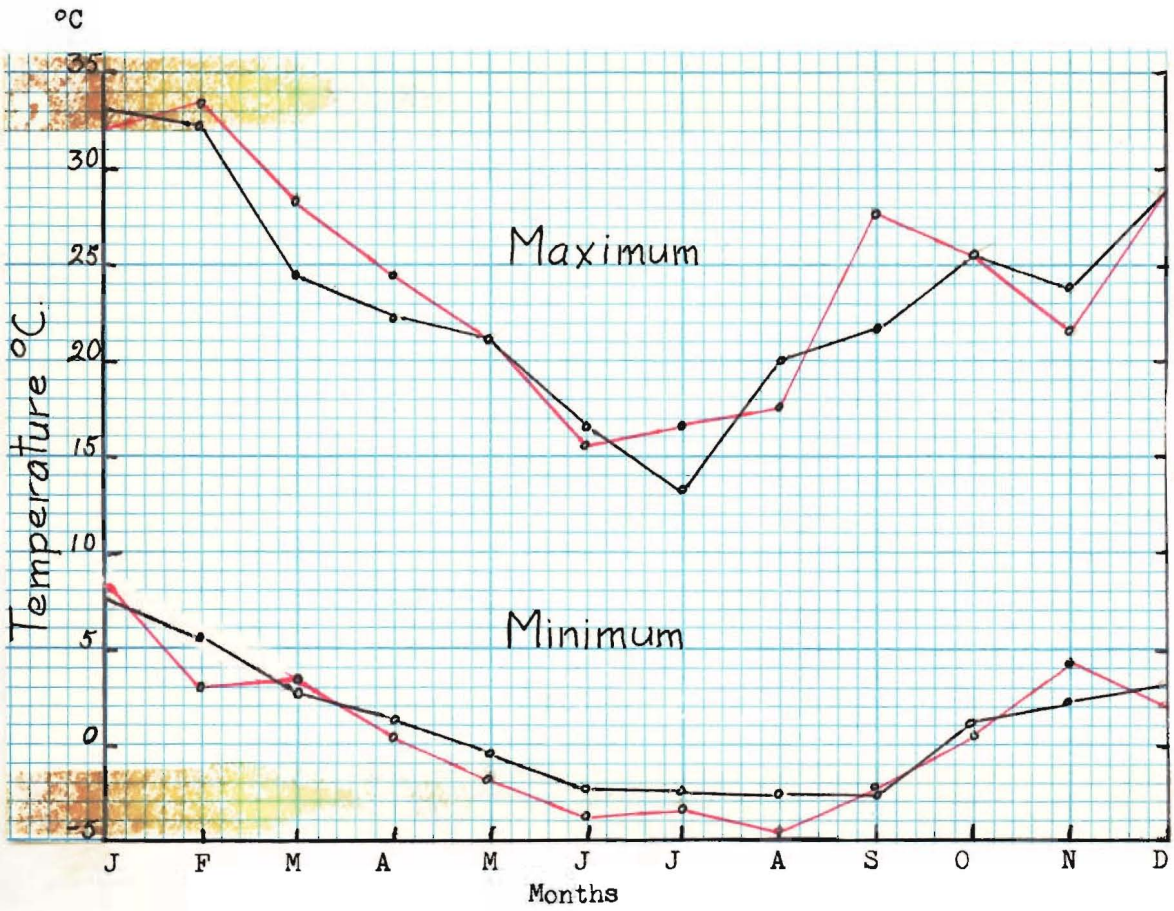


Fig. 17. Screen temperatures, monthly maxima and minima, 1971, at Lincoln meteorological station, ——, and Kaitorete study site, ——.

(iii) 10cm below the surface, placed horizontally inside an 8cm diameter steel tube, open at both ends; this was buried under soil and vegetation typical of the site, leaving a protruding tagged wire as a marker.

These thermometers were read between 10.00 a.m. and noon at regular intervals of four weeks, from 6 March, 1971 to 12 March, 1972. For purposes of comparison with meteorological stations it would have been better to read these at the end of each month, but this was not possible, since visits were only practicable on week-ends, owing to work commitments on weekdays.

Before installation, all thermometers were calibrated by exposure to daily extremes of temperature and comparison with a standard mercury-in-glass thermometer. Only those instruments varying less than $\pm 1^{\circ}C$ from the standard were used.

During August, 1971, one thermometer was removed by vandals; it was replaced by a new one the following week.

A summary of monthly maximum and minimum temperatures for 12 months, for all five microstations is given in Appendix II, Table 1. Figures 14, 15, 16, show comparisons of monthly maximum and minimum temperatures at all five stations in air, at surface, and in soil. The monthly maximum and minimum screen temperatures, with those recorded at Lincoln for comparison, are given in Fig. 17.

Some continuous weekly records of air temperature and humidity were obtained by the use of thermo-hygrographs. Four of these, of the type combining a bimetallic strip thermometer with a human hair hygrometer, were installed at stations A, B, C and D, protected inside louvred white wooden boxes. Runs were made, commencing on the following dates:

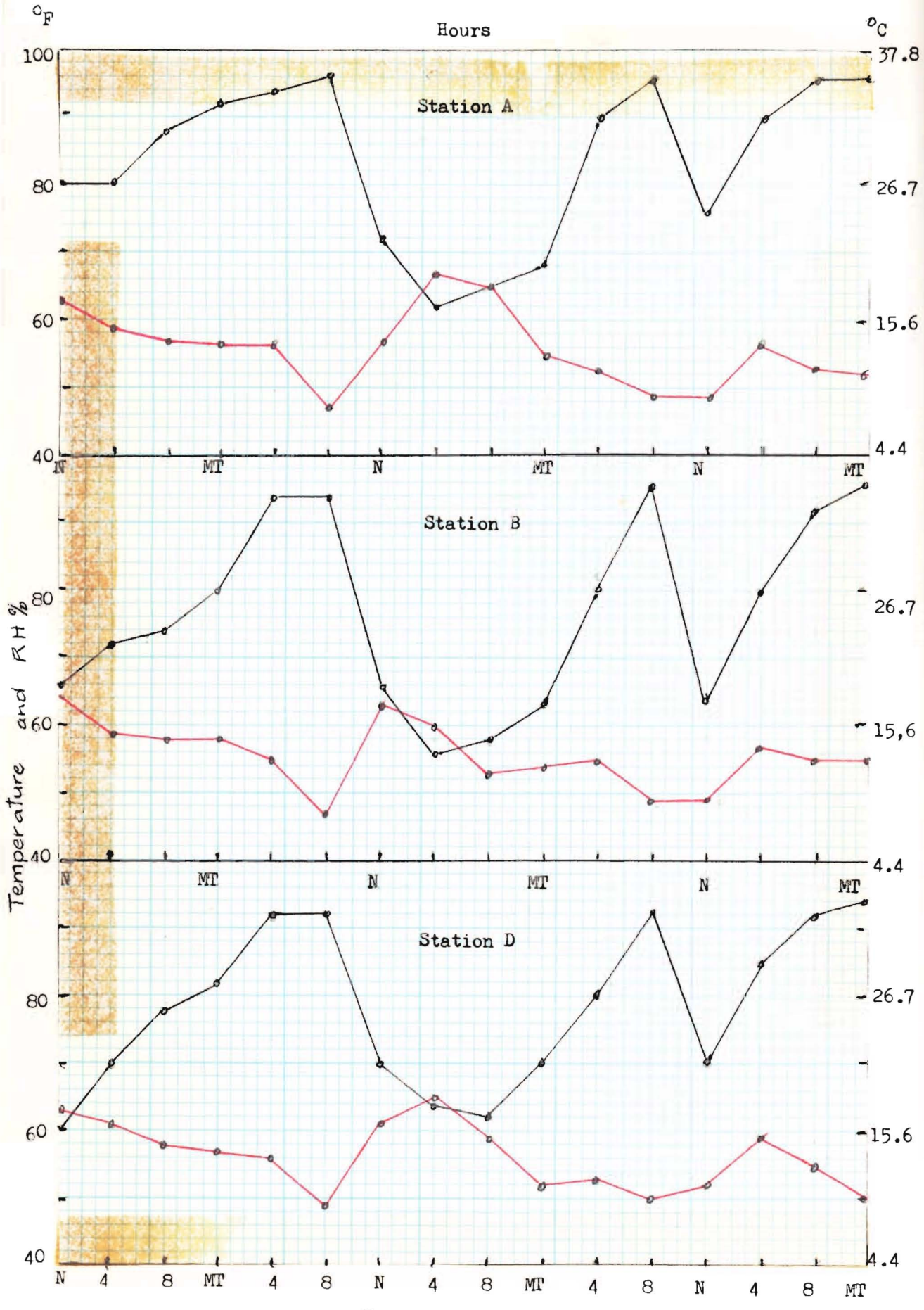


Fig. 18. Temperature and relative humidity% at three microstations in winter, 1971.

Temp. ——— , RH% ———

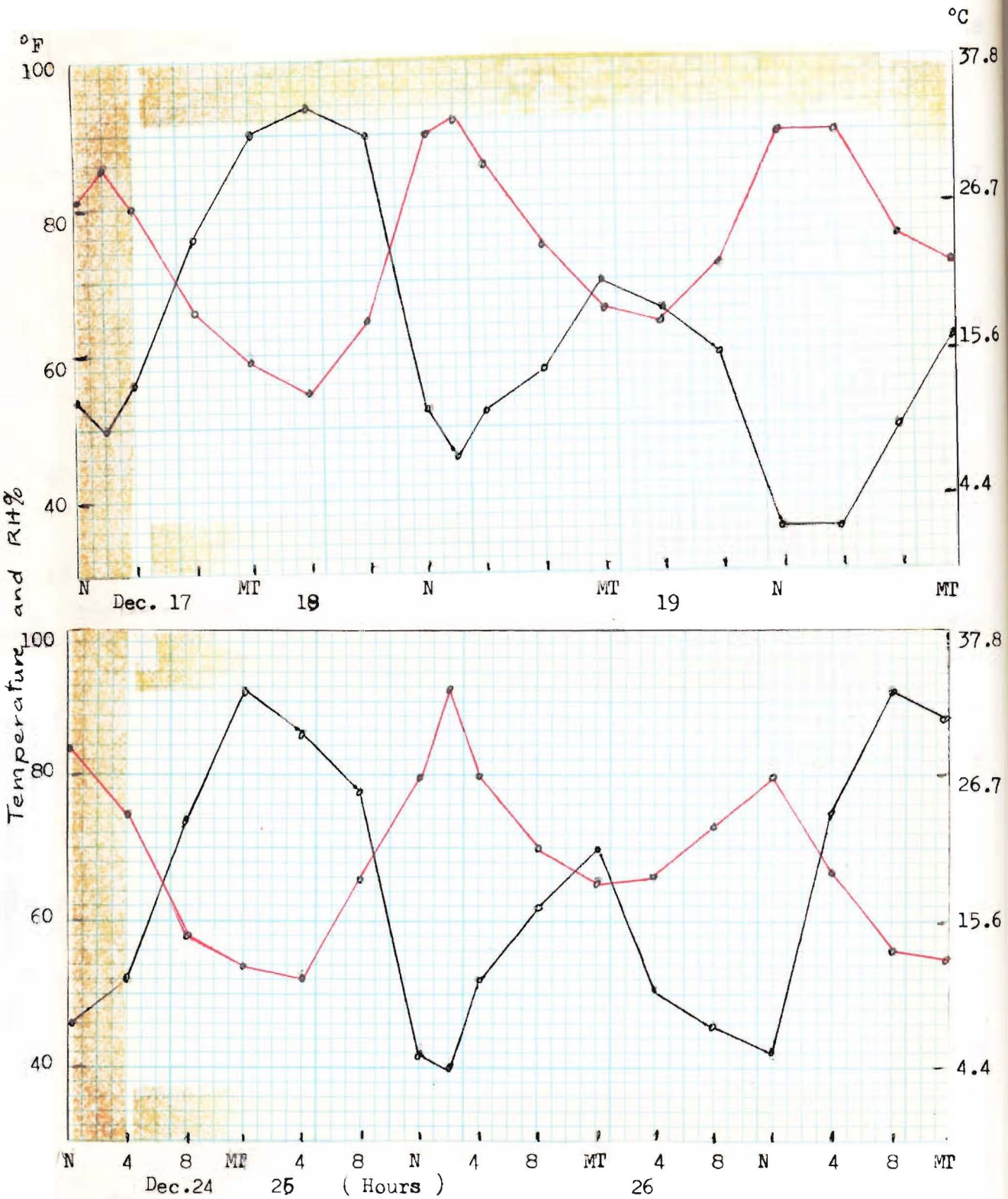


Fig. 19. Temperature and relative humidity at microstation C, summer, 1972.

Temp. —— ; RH% —— .

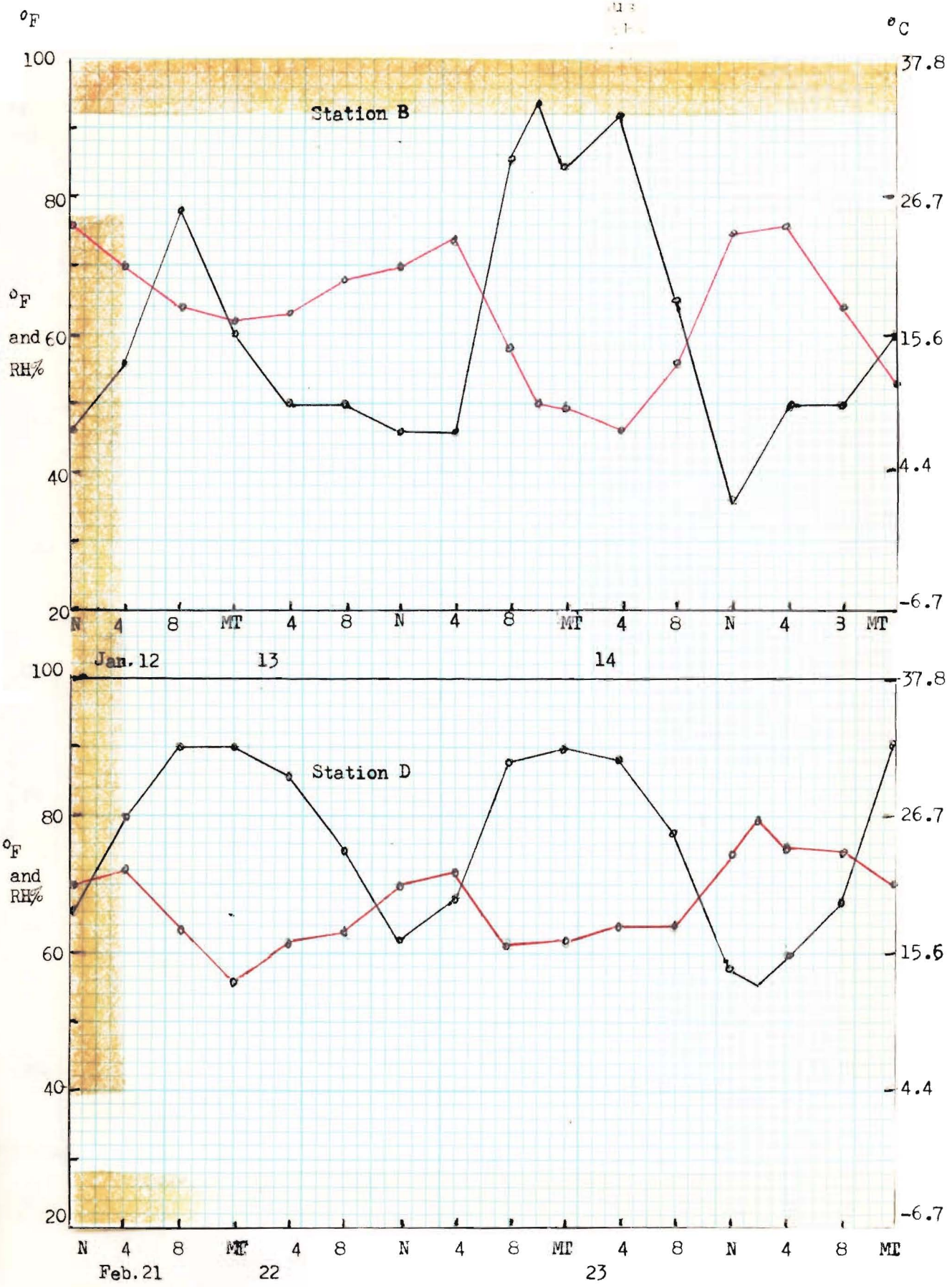


Fig. 20. Air temperature and relative humidity at two microstations in summer, 1972.

Temp. ——, RH ——— .

27. 2.1971 (A, B and D only)
11. 5.1971 (A, B and D only)
1.12.1971
14.12.1971
23.12.1971
9. 1.1972
20. 2.1972 (A, C and E only)

Insufficient instruments were available to include station E, for which only one run was made on 20.2.1972, using the instrument from B.

Some of the results are graphed in Figs. 18, 19, 20, and others are summarized in Appendix II, Table 2.

NOTE ON THERMOHYGROGRAPH RECORDS FOR MICROSTATIONS 1971-72

In April, 1971, these instruments were carefully checked over a running period of several days out-of-doors in Christchurch, and adjusted so that they were all synchronised with temperature and humidity read from a standard mercury-in-glass thermometer, and whirling psychrometer respectively.

After installation of three instruments at the study locality in May, checks were again made during the runs, and small necessary adjustments made to the temperature sensors. Humidity readings seemed to be fairly satisfactory.

The instruments were then collected and returned to the University. On 1 December, 1971, four other instruments were installed at the study locality, again after making a trial run of several days out-of-doors in Christchurch during November, and adjusting so that all instruments were synchronised with standard thermometer and whirling psychrometer readings. It should be noted, however, that the range of both temperature and humidity was not very great at the time, in the place where the trial was carried out, so that the accuracy of the instruments at extremes of temperature and humidity was not able to be checked rigorously.

During subsequent runs on 1 December, 14 December, 23 December, 1971, it was observed that instruments at stations A, B and D consistently gave much lower maximum humidity readings (about 20% less) than the maximum readings of instrument at C. Before the graph sheets were collected, the temperature and humidity readings at the time were checked against standard thermometer and psychrometer. Checks were also made at the start of each run. Some adjustments to the hygrograph arm were made as seemed necessary, but anomalies continued to appear. (Temperature sensors were all recording satisfactorily.)

On 9 December all instruments were moved to the shelter of the hut at 10.00 a.m. and further attempts were made to synchronise the humidity recorders by making

adjustments over a period of two hours. Because of the anomalous behaviour of all humidity recorders, except for the instrument at C (which correlated closely with the mercury-in-steel thermohygrograph set up below the Stevenson's screen), it was decided to try changing the instruments around. Accordingly, on 9 January, the instrument from C was placed at station B, and on 20 February it was placed at D. Results confirmed that the lowmaximum humidities previously recorded at these stations were erroneous.

Consequently, it appears that, although all temperature records are fairly reliable throughout, the humidity records are only reliable for C on 1, 14 and 23 December, and for B on 9 January, and D on 20 February.

For all other records, the humidity readings are reasonably reliable between 40% and 68%, but do not record extremes below and above these figures.

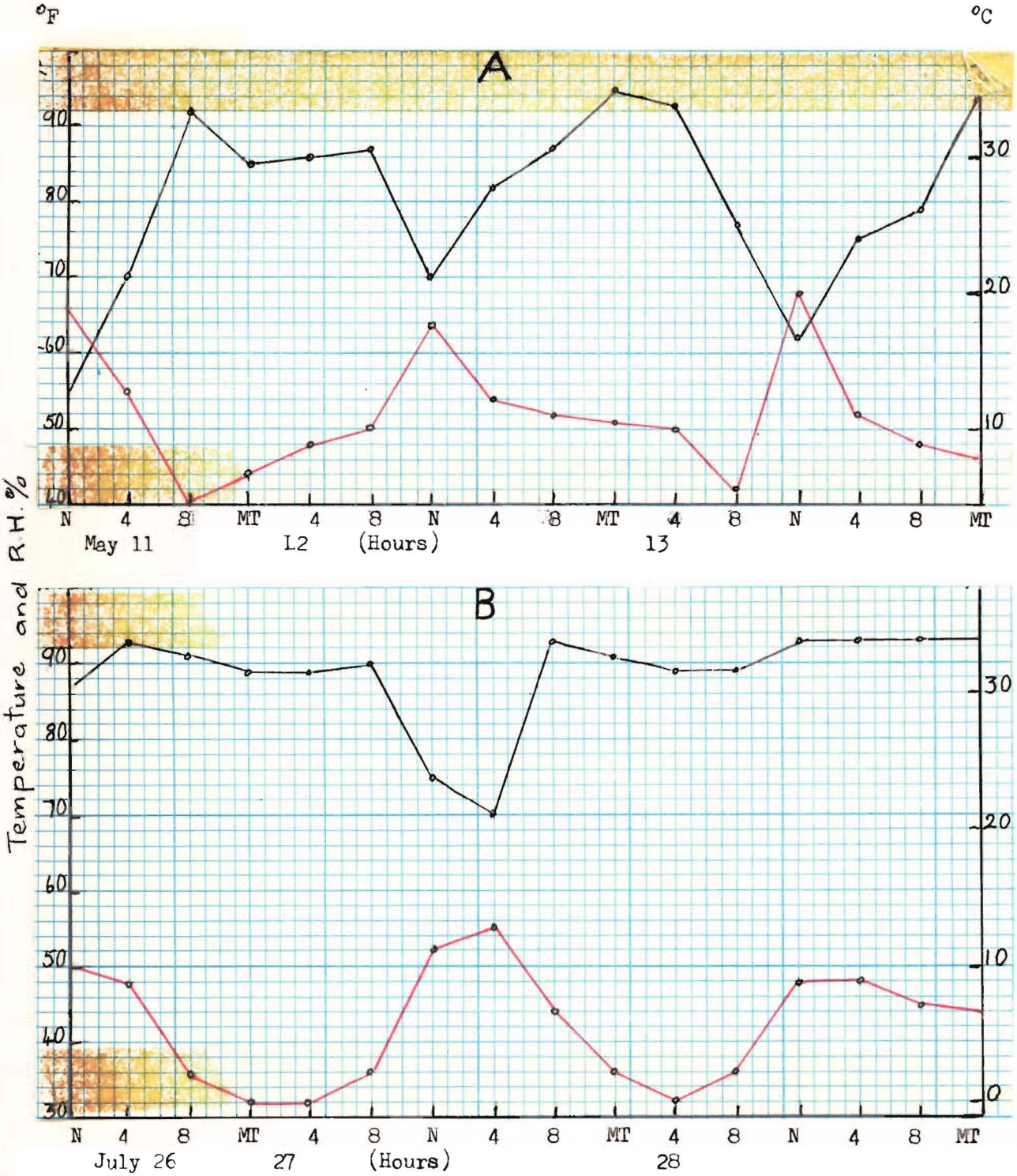


Fig. 21. Temperature and relative humidity in winter, recorded below Stevenson's screen at study site.
A, May 11-13, 1971; B, July 26-28, 1972.
Temp. —— ; RH% —— .

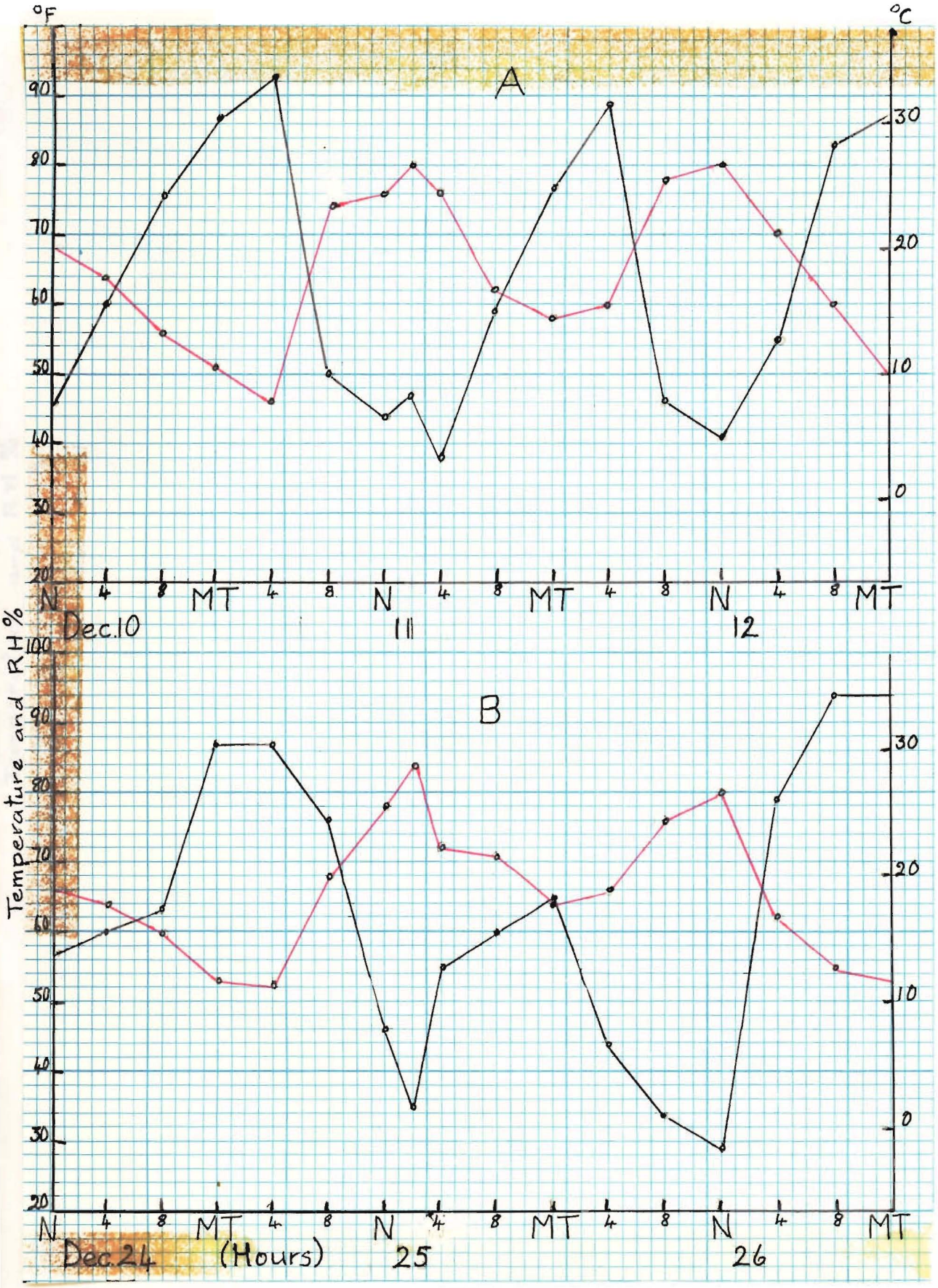


Fig. 22. Temperature and relative humidity in summer, recorded below Stevenson's screen at study site.

A, Dec.10-12, 1971; B, Dec.24-26, 1971.

Temp.— ; RH% — .

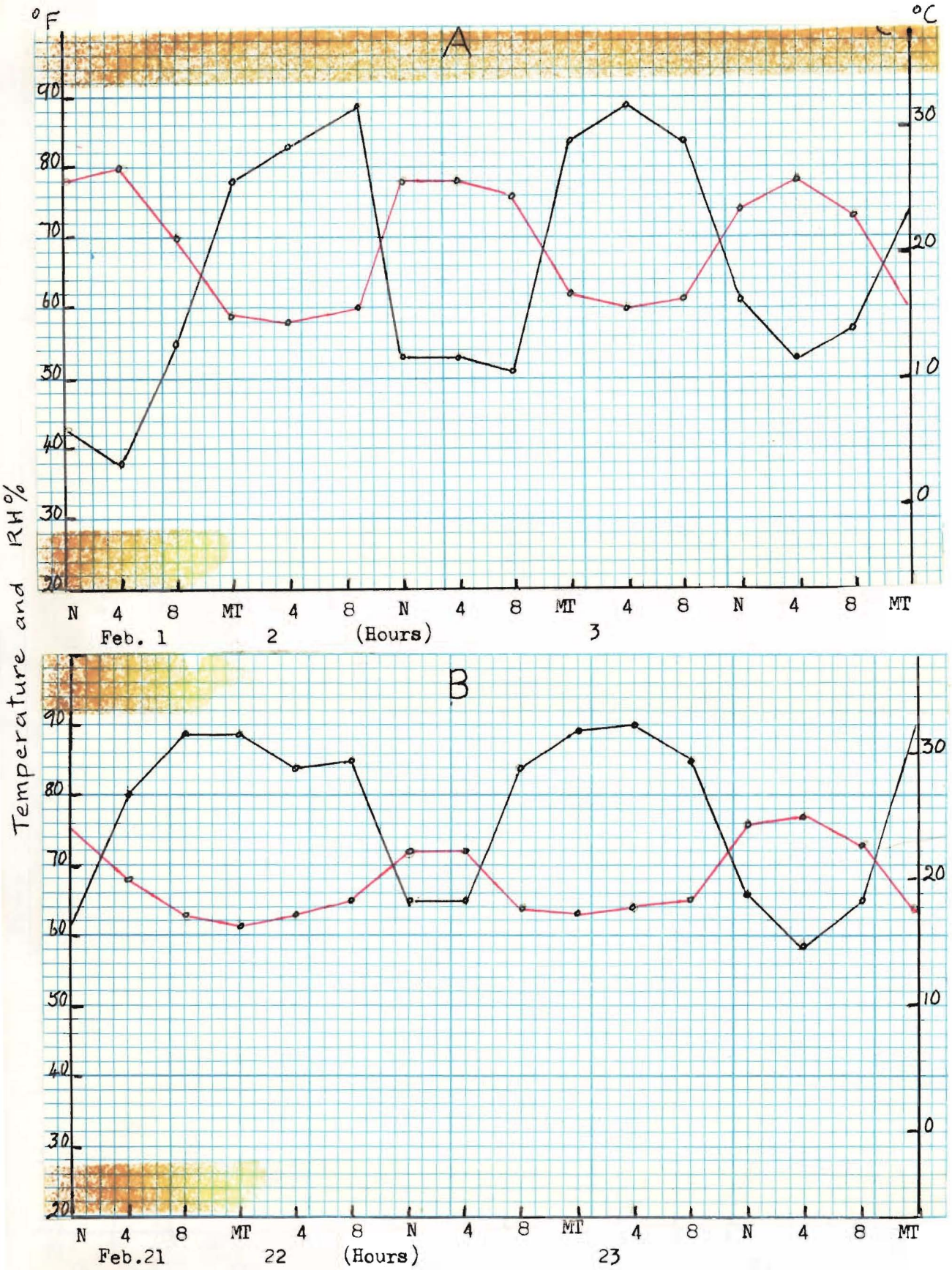


Fig.23. Temperature and relative humidity in summer, recorded below Stevenson's screen at study site.

A, Feb.1-3; B, Feb.21-23, 1972.

Temp. —— ; RH% —— .

Below the Stevenson's screen, a wet and dry mercury-in-steel thermohygrograph was installed; it was sheltered by malthoid strips above and at the sides, to protect it from rainfall and direct radiation, while allowing ample air circulation. Runs were made commencing on the following dates:

11. 5.1971; 9.12.1971; 14.12.1971; 23.12.1971;
9. 1.1972; 22. 1.1972; 29. 1.1972; 20. 2.1972;
25. 7.1972; 1. 8.1972; 13. 8.1972.

Results are summarized in Appendix II, Table 3, and representative records for different seasons are graphed in Figures 21, 22, 23. Appendix II, Table 4, shows diurnal fluctuations of temperature, relative humidity and vapour pressure deficit, for five periods, representative of winter and summer conditions.

Continuous weekly records of soil temperatures at depths of 10 and 20cm, were made with mercury-in-steel thermographs installed at stations A, B and D (insufficient instruments being available for all five stations). Runs were made commencing on the following dates:

27. 2.1971; 11. 5.1971; 1.12.1971;
14.12.1971 (results not available)
23.12.1971; 9. 1.1972.

Before installation, all instruments were checked against a standard mercury-in-glass thermometer.

Results are summarized in Appendix II, Table 5. Weekly extreme maximum and minimum temperatures have been graphed for one period in winter and three in summer. (Figures 24, 25). Diurnal fluctuations over a 60 hour period in March, 1971, are graphed for three stations in Fig. 26.

A continuous week's record of soil temperatures at four depths (5, 10, 20 and 50cm) was made with two thermographs, installed near the Stevenson's screen, on 10 February, 1972. Results are given in Appendix II, Table 6, and Fig. 27.

Discussion:

Monthly screen temperatures at the Spit during 1971 were generally higher than at Lincoln (sometimes as much as 5°C), although occasionally slightly lower (Fig. 17).

Comparing monthly maximum and minimum air temperatures at the different stations across the Spit (Fig. 14) the lowest minimum was always at E (predictably, as this is farthest from the sea), while the highest minimum was virtually always on the fore dune, the difference being from 5.5° to 10.5°C. Other stations showed irregular fluctuations between these extremes. The lowest recorded was -7.5°C, in August, 1971. Maximum air temperatures showed less variation, especially from June to October, although the fore dune remained about 2.5°C cooler than other stations during this period. From September onwards throughout summer the highest temperatures were reached at E (from 2.7° to 6.7°C higher than other stations during December), presumably because this site was the least exposed to cooling breezes, from the sea. The highest figure reached was 37°C.

Temperatures at the ground surface (Fig. 15) showed a much wider range in maxima, which were generally several degrees higher than in air in summer and one or two degrees lower than air in the coldest period. The maximum surface temperature of 37.5°C occurred at B in January. Minimum surface temperatures showed little difference from minimum air temperatures, except those at E were not so much lower, presumably because of the insulating effect of the vegetation. The lowest minimum of -6.5°C occurred at E in September. In 1972, when thermometers were no longer in use, the Spit was visited on 29 June, at 3.00 p.m., after a ground frost of -8.2°C had been registered at Lincoln; though the day had been sunny, the sand was found to be frozen hard to a depth of 2.5cm in the shaded parts of all sites, including the fore dune.

Soil temperatures (Fig. 16) predictably showed a much smaller range between maxima and minima than did air and surface temperatures. Minima for all stations were

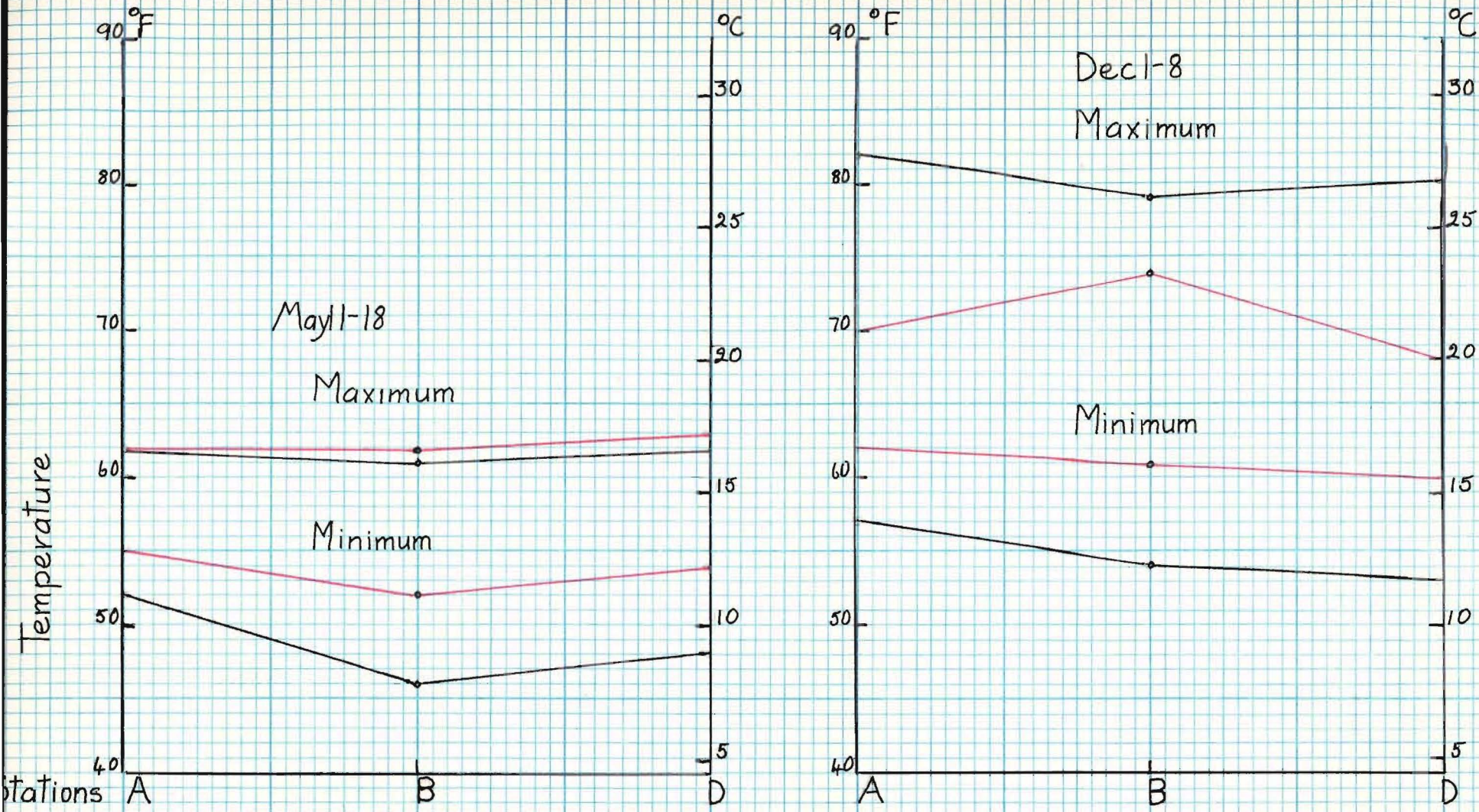


Fig. 24. Comparison of maximum and minimum soil temperatures at 10 and 20 cm. depths, at three stations, weekly extremes, May 11-18 and Dec 1-8, 1971. — 10 cm. — 20 cm.

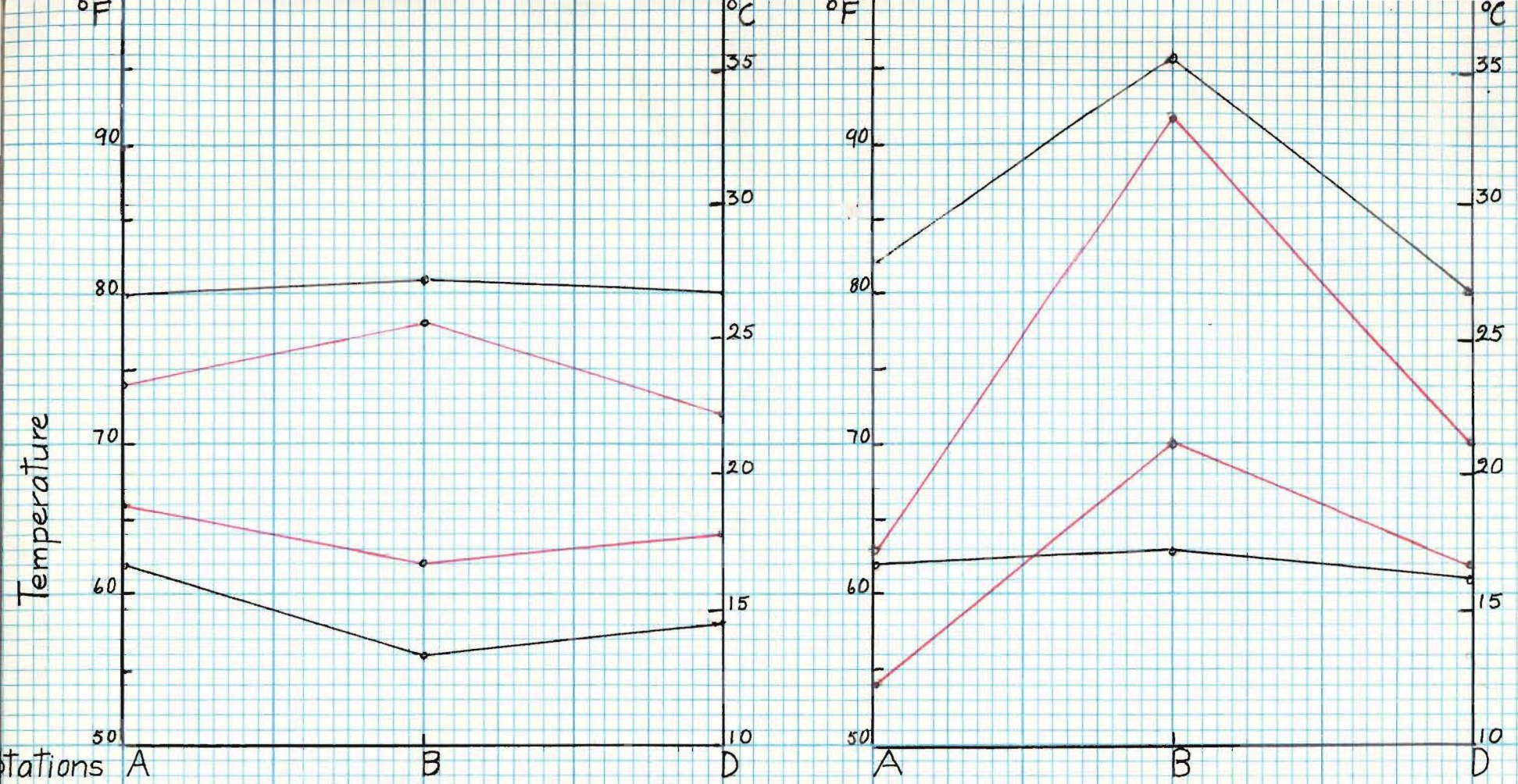


Fig. 25. Comparison of maximum and minimum soil temperatures at 10 and 20 cm. depths at three stations, weekly extremes, Dec. 23-30, 1971, and Jan. 9-16, 1972. — 10cm. — 20 cm.

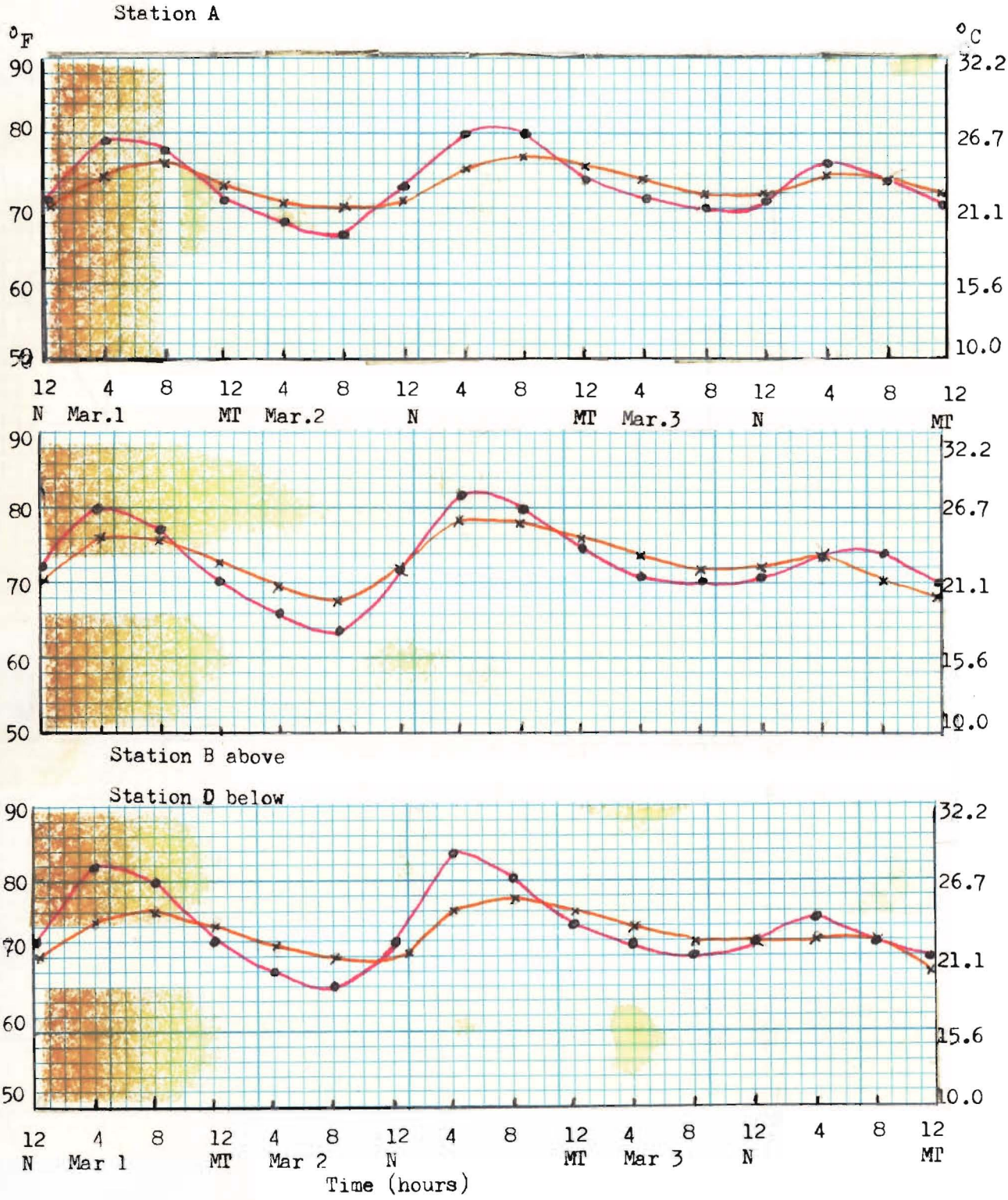


Fig. 26. Fluctuations in soil temperatures, at stations A, B and D, over a continuous 60 hour period, Mar 1-Mar 3, 1971, at two depths; 10 cm —— . 20 cm ——.

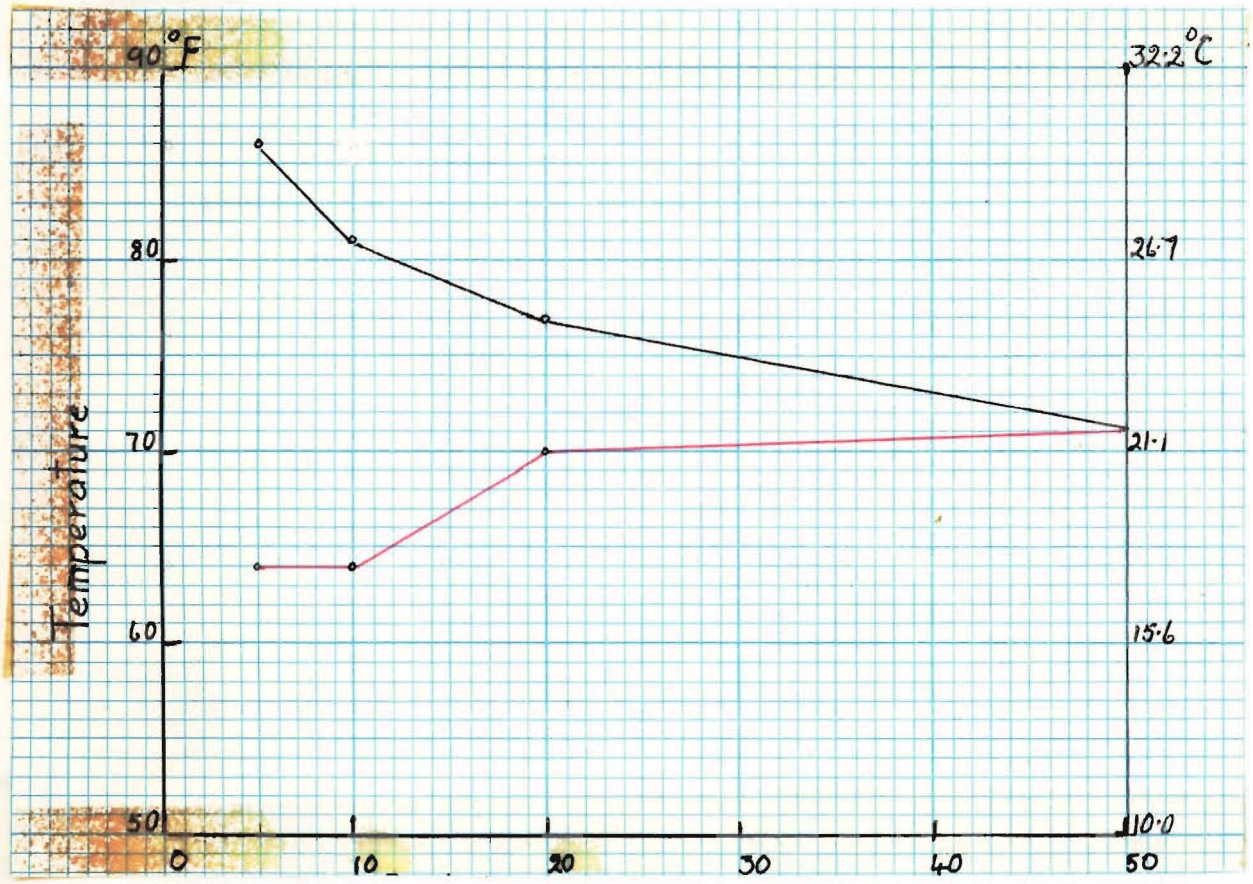


Fig. 27. Soil temperatures at increasing depths, 5, 10, 20 and 50 cm, extreme maxima and minima recorded for a week, 10 Feb.-17 Feb. 1972.

similar, the lowest (about -2°C) occurring in August. Maxima varied somewhat unpredictably between stations. Highest temperatures at B from July to October possibly reflect the high specific heat of water, as this site remains the wettest near the surface, and drier sites would be more affected by night cooling. The low maximum at E might be due to the vegetation reducing insolation. Highest maximum of 32°C occurred at B, C and D in December-January.

In general the above findings agree well with the principles relating to microclimate as discussed by Geiger (1950).

* It is to be noted that Oosting (1945) reported no significant differences in the temperature of dune soils at a number of stations from fore dunes to rear dunes.

Consideration of soil temperatures at 10 and 20cm depths (Figs. 24, 25) shows that in winter at both levels there is little difference between maxima at stations A, B and D, but minima are higher at A (as might be expected from its proximity to the sea). In summer, at 10cm, B has the lowest maximum, while at 20cm it has the highest maximum; this would seem to be correlated with its water content (slow to absorb radiant heat near the surface and slow to lose stored heat from lower down).

The expected insulating effect of soil 20cm deep compared with 10cm is illustrated in Fig. 26. Temperatures at the greater depth show maxima 1.4°C lower, and minima 2°C higher than those at the lesser depth. There is also a two hour lag in the attainment of maxima at the lower depth, though little difference in the time of reaching minima.

Fig. 27 illustrates how the range of diurnal fluctuation in soil temperatures decreases with depth (very abruptly at 10cm), until a point is reached at 50cm when a steady temperature prevails throughout 24 hours. This agrees with the findings of Geiger (1950), Salisbury (1952), Willis et al (1959) and Migahid (1961).

Diurnal fluctuations of temperature and humidity measured at three stations in winter (Fig. 18) revealed insignificant differences except that at A, between noon and 4.00 p.m., humidity was slightly higher than elsewhere. Since only one of the thermohygrographs functioned efficiently for extremes of humidity, there are no figures from which to compare the difference in stations at any one period in summer. However, at stations B and C during December and January, maximum temperatures of about 34°C and minimum RH of about 46% occur at approximately 2.00 p.m., while minimum temperatures of about 12°C and maximum RH of about 92% occur at approximately 4.00 a.m. (Figs. 19, 20).

Seasonal differences in air temperatures and RH% were recorded more reliably by the wet and dry steel bulb thermohygrograph below the Stevenson's screen (Figs. 21, 22, 23). In winter (May, 1971) the minimum temperature of 4.4°C and maximum RH of 90-95% occurred between 4.00 and 8.00 a.m.; maximum temperatures of 18-20°C and minimum RH of 62-70% occurred at noon. In July, 1972, lower temperatures, down to 0°C, and a generally higher level of humidity were recorded. In early summer (10 December) a maximum temperature of 26°C and minimum RH of about 40% were recorded at noon; minimum temperatures of 8-10°C and maximum RH of 85-90% occurred between midnight and 4.00 a.m. In late summer (February) the fluctuations of temperature and humidity became much less extreme, and the highest temperatures occurred later, between 2.00 and 4.00 p.m.

It is to be noted that in winter there is a range of about 16°C in temperature and 30% in RH; in summer a range of about 18°C in temperature and up to 60% in RH.

Vapour pressure deficit is probably the most meaningful parameter to consider. If a VPD higher than 5mm is arbitrarily taken as likely to have a significant effect on the plants, it can be seen from Appendix II, Table 4 that deficits of this order prevail for at least 13 hours per day (sometimes for 24 hours continuously) during summer, and for several hours per day in late autumn.

DEW AND CONDENSATION OF WATER VAPOUR IN SOIL

Reference to these factors is made at this point because of their dependence on temperature and humidity.

Many authors have pointed out that not all the moisture in a sand dune or shingle beach is conserved rain water (Geiger, 1950, Salisbury, 1952). Even in the driest summers, when no rain has fallen for weeks, damp sand can be found a foot below the surface of a dune, and the same applies in deserts where no rain has fallen for years. It has been demonstrated that capillary movement of water from the water table can account for only 382mm rise in 8 weeks through fine sand (0.03-0.05mm grains), and only 188m through coarse sand (0.3 - 0.5mm grains) according to experiments by Olsson-Seffer (1909). Thus a significant proportion of the moisture present in sand must often be contributed by the downward movement of dew formed at the surface, and by upward movement of soil water vapour which condenses in a cooler stratum. This phenomenon of internal condensation has been cited as an important factor in maintenance of water balance of dune plants. Low water content and large pore spaces make sand a poor conductor of heat. When the soil surface is cooler than air, and humidity is high (as at night in summer), conditions are ideal for movement of aerial water vapour downward, to condense at the soil surface and be absorbed. Also, when the upper layers of sand are warmer and drier than deeper layers, subterranean water vapour moves upward (e.g. on hot days), condensing when the surface temperature drops at night.

Since no systematic investigations were possible in the present study, reference will be made to some of the findings of other workers, whose methods were based on weighing samples of soil in sieves or dishes set into the surface of the soil, at regular intervals from late afternoon to early morning.

Ramdas and Katti (1934) found the percentage of water in bare surface sand twice as great in the early morning as

in the previous afternoon. Lébedeff (1928) described semi-arid region in South Russia in which 66mm of water was moved to the surface from deeper layers of the soil in one winter. Brawand and Kohnke (1952) in Indiana found a net soil moisture gain, from vapour in the atmosphere, of 58.4mm per year, from analysis of surface samples; of this 32% was received in summer, the remainder being spread equally over autumn, winter and spring. Some authors have reported up to 250mm of soil moisture per year gained in this way in oceanic climates. Migahid (1961) concluded that in a semi-arid coastal Mediterranean region soil moisture gains from this source were critical to plant survival; Muller-Stoll and Lercher (1961) came to the same conclusion.

From personal observations at the Spit, very heavy dews occurred at the surface in autumn and winter; after a fine clear night both sand and foliage were frequently still wet with dew even at 10.00 a.m. In summer, similar observations were made on two occasions between 5.00 and 7.00 a.m., but after that hour dew rapidly evaporated.

It would appear that the wide extremes and rapid changes of temperature and humidity at the Spit would frequently provide ideal conditions for surface dew and internal condensation, and that this is likely to be an important source of soil moisture in critically dry periods.

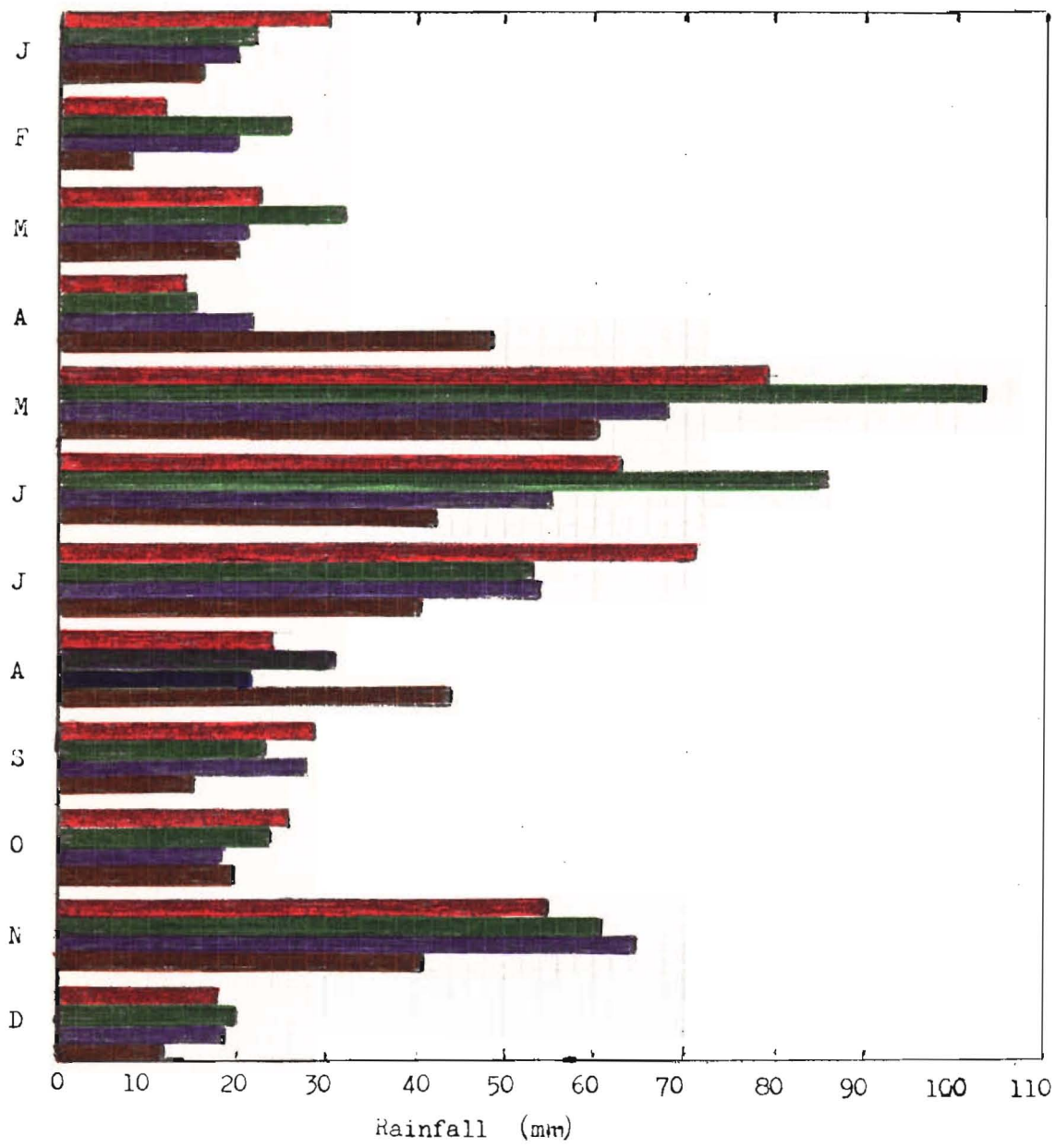


Fig. 28. Monthly rainfall, 1971, recorded at Lincoln and at three locations at Kaitorete.

Lincoln ——, Hammond's ——, Bayley's ——, Study site ——.

(b) PRECIPITATION

Rainfall was measured in a standard rain gauge of 12.7cm diameter, sunk into the ground with the top 12cm above ground level, 1.5m to the east side of the Stevenson's screen. During the summer, after each measurement, 25ml of water, plus a few drops of kerosene, were placed in the gauge to reduce loss by evaporation (the same amount being deducted from the next total).

Rainfall was recorded at four-weekly intervals (which was a disadvantage for comparison with other meteorological records, but was unavoidable for the reasons stated earlier), from 1 February, 1971 to 1 April, 1972.

Results of these measurements are shown in Appendix II, Table 7, which also gives monthly and annual figures for Lincoln, and for Hammond's and Bayley's homesteads (at the eastern end and middle of the Spit respectively), during 1970, 1971 and 1972. Annual totals at Lincoln and at Bayley's over a nine-year period from 1964 to 1972 are given in Appendix II, Table 8. Figure 28 shows a comparison of rainfall in 1971 for Lincoln, Hammond's, Bayley's and the study area. Figure 32 shows monthly rainfall at Lincoln in relation to PE for 1971.

Measurements of dewfall, and internal condensation within the surface layers of the soil were not undertaken, although they would have been of great interest. The difficulties involved in obtaining data would have been considerable, as frequent sampling between early evening and early morning, on a number of occasions, would have been necessary. Only one overnight stay was possible, and on that occasion conditions proved unsuitable for dew formation (but note comments on dew and condensation at end of previous section).

Discussion:

Comparison of nine-year means for rainfall at Lincoln and at Bayley's homestead (Appendix II, Table 8) indicates that the Spit receives only about four fifths of the rain

measured at Lincoln. With a mean of 515mm per year, and lowest records of 384mm (1969) and 410mm (1964), the climate of the Spit comes into the semi-arid class (c.f. Central Otago which has a mean annual rainfall of less than 500mm). Measurements at the study locality show an even lower rainfall than at Bayley's. The higher figures at Bayley's might possibly be related to the shelter belts which reduce wind and associated evaporation in the vicinity of this rain gauge. Rainfall at Hammond's homestead, which is at the extreme eastern end of the Spit and close under the S.W. slope of Banks Peninsula, is predictably higher than on the dune area or at Lincoln, since the climate of the Peninsula is well known to be wetter than the surrounding countryside.

Although on the average the highest rainfalls at the Spit occur between May and September, there can sometimes be long dry periods during winter and early spring. Alternatively, there can sometimes be a month of high rainfall in late summer, as in March, 1970 (Appendix II, Table 7). Much of the rain falls in light showers, so that it is intercepted by foliage, or wets only the top few centimetres of the soil, and its value for the plants is almost entirely negated when conditions favouring high evaporation rate prevail, especially from October to March. Soil conditions thus remain considerably moister during winter, even if the rainfall is low, because of higher humidity and lower temperatures. Fogs are not uncommon.

(c) WIND

This was recorded by means of a standard Robinson's three-cup (12.7cm diameter) anemometer, mounted on iron piping at a height of 2.5m. The instrument was firmly supported by wiring it to one corner of a small wooden hut (only 1.3m high, and, therefore, causing negligible interference), in a situation at the north-eastern edge of the interdune flat marked by Station B. As with temperature and rainfall, readings (of miles run) could be made only at four-weekly intervals. This, together with the comparatively low positioning of the instrument, makes direct comparison with monthly results from Lincoln unsatisfactory. However, the mean daily miles run (24-hour period) has been calculated for each month, and these figures are included in Appendix II, Table 9 for the period March, 1971 to February, 1972. This and Fig. 29 give some idea of the comparative windiness throughout the year at the study locality.

In an attempt to compare wind speeds at various heights, and at different stations, some readings were made from an air-meter, recording km run for five-minute intervals. Readings were made at four heights (ground level, 10cm, 30cm, and 60cm) at each station on 28 February and 12 March, 1972. These figures are not particularly valuable because of the highly variable, gusty nature of the wind, and the impossibility of taking simultaneous readings for all heights at all stations. Results are shown in Appendix II, Table 10, and also in Fig. 30.

The percentage frequency of surface wind directions at Lincoln for 1970, 1971 and 1972 is given in Appendix II, Table 11.

Discussion:

As shown by Fig. 27, mean monthly wind (as miles and km run per 24 hours) at the Spit closely parallels that at Lincoln. The anemometer at the Spit was set at a height of 2.5m compared with a height of 5.1m at Lincoln.

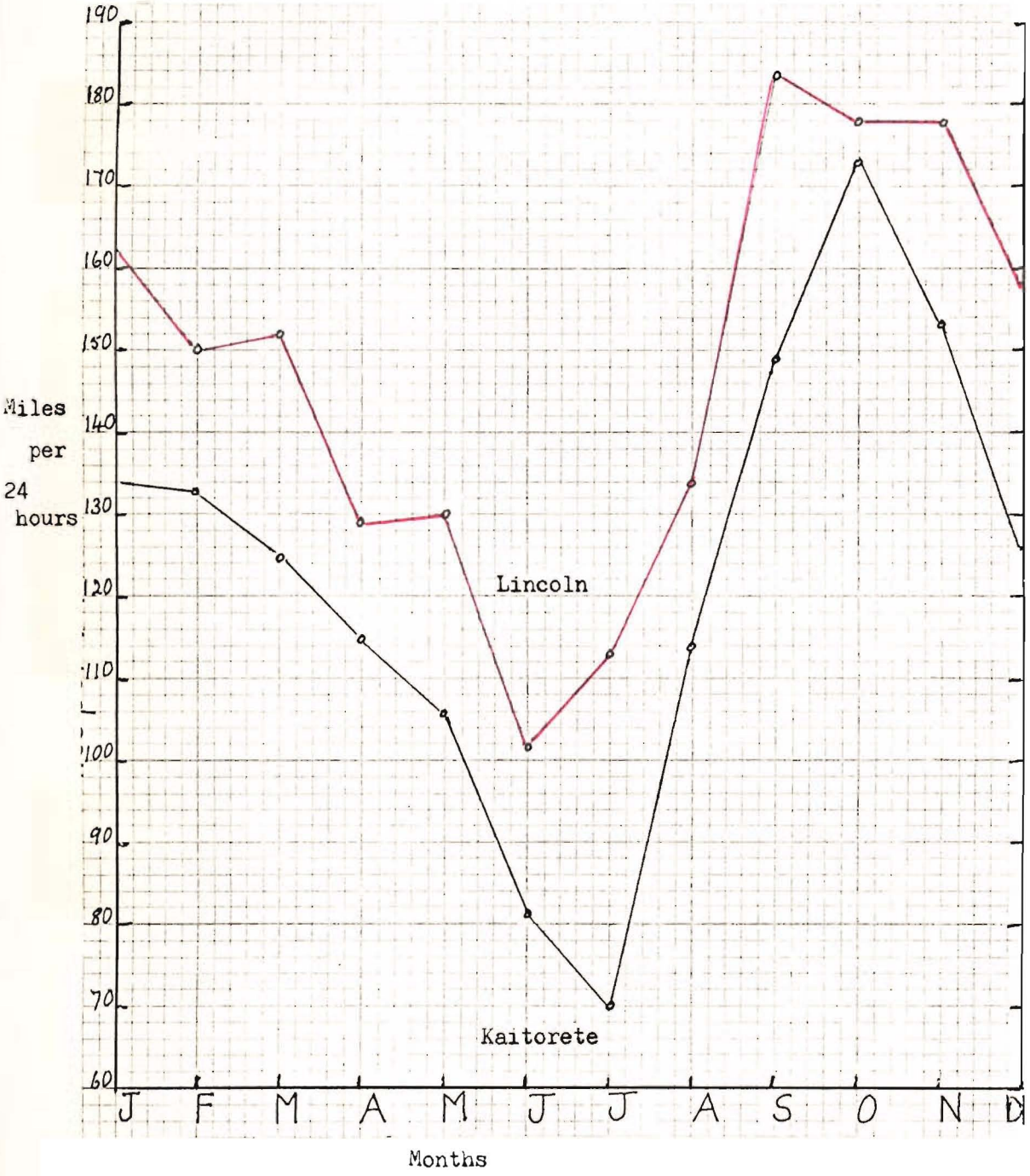


Fig. 29. Wind calculated as miles per 24 hours (monthly means)1971, at Lincoln meteorological station,anemometer 6 m above surface, and at study site,Kaitorete,anemometer 2.5 m above surface.

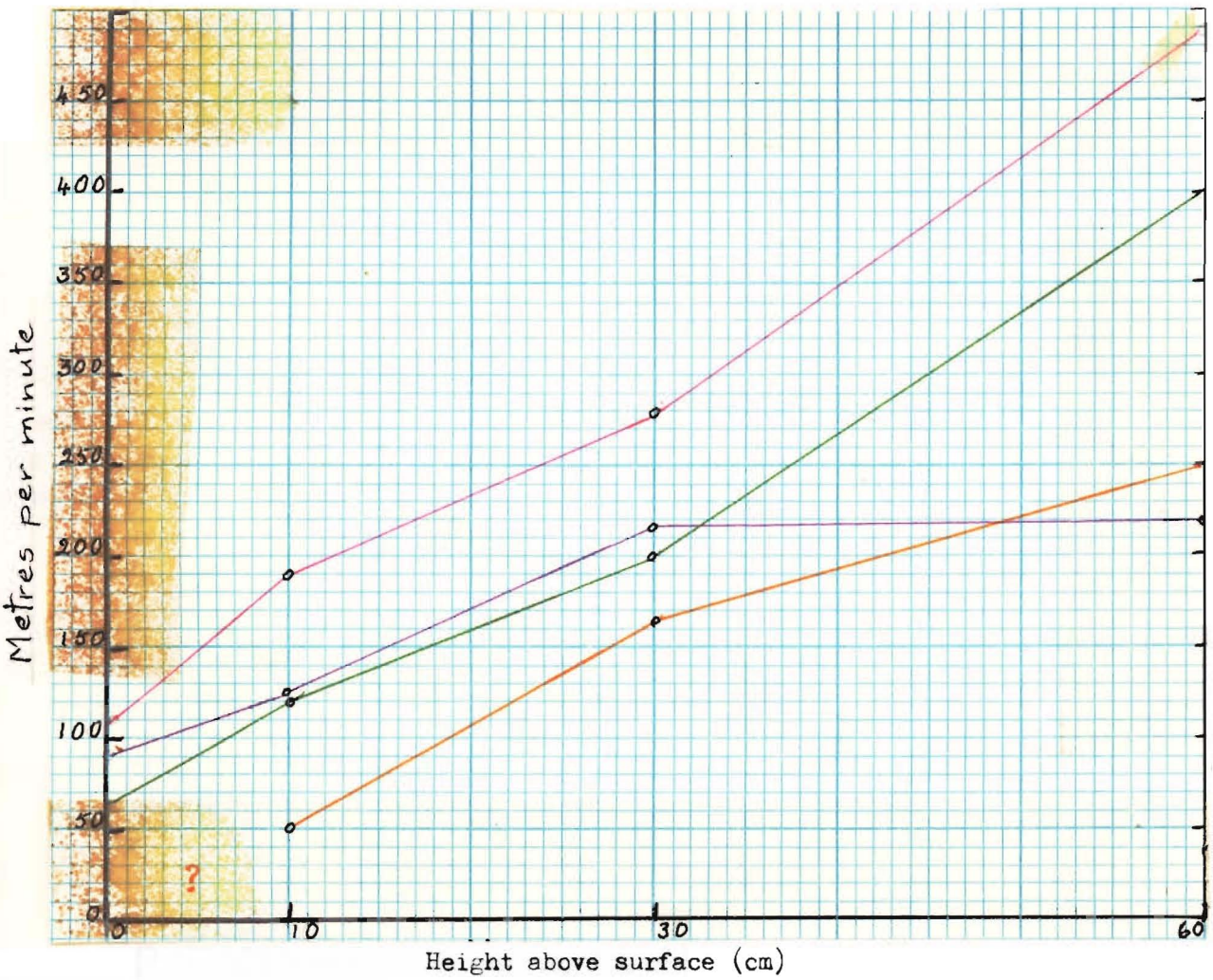


Fig. 30. Wind speeds recorded at microstations at four heights, from ground surface to 60 cm above, noon to 3 pm, 28 Feb. 1972. Station A —— , B —— , C —— D —— .

Using the formula

$$V2.5 = V5.1 \left[.233 + .656 \log (2.5 + 4.75)\right]$$

where V2.5 = wind speed at 2.5m

V5.1 = wind speed at 5.1m *

an annual mean for the Spit, measured at 5.1m, would be 155 miles per 24 hours, compared with 148 for Lincoln. Comparing this figure with wind data from sea-level meteorological stations throughout New Zealand it would appear that the Spit is a relatively windy place.

The winter months of May, June and July have the lowest wind totals, although gale force winds from the south-west commonly occur at this season (e.g. 962 miles run in a 24-hour period in April, 1968 represents an average of 40 m.p.h.).

Although the analysis of wind directions (Appendix II, Table 11) shows the prevailing wind to be NE, the most important wind direction is SW (winds from N and NW occur less commonly). It is this SW wind which is responsible for the distinct SW-NE orientation of the longitudinal dunes (clearly seen in Figs. 2, 3, 4), and for the "wind-shorn" appearance of the shrubby vegetation (shown in Figs. 57, 59, 61, and discussed in Ch.4, Section 5).

No figures were obtained for the highest wind speeds reached at the Spit, during the study period, but on several occasions the south-westerly was estimated to be of force 7 or 8 (between 32 and 45 m.p.h.). The strongest wind recorded by the Meteorological Service at Ellesmere is 91 m.p.h. From the few measurements made with the wind meter (Fig.30), a predictable increase in velocity was noted as height increased from ground level to 60cm, although the impracticality of taking simultaneous readings leaves these figures open to question (e.g. the non-increasing figure for the 60cm height at the blowout was almost certainly due to an overall sudden drop in wind force).

Studies by Olson (1958b) and Ranwell (1958) have

---

* Formula supplied by the Meteorological Office, Harewood.

indicated that maximum wind velocities occurred near the crest of the windward face of a coastal transverse dune. Some protection was afforded immediately in front of the dune and on its lower windward slopes. Beyond the crest, on the lee slope was a calmer area where deposition occurred, while beyond the shelter of the dunes, on inter-dune flats to landward, wind velocities increased again, building up to another maximum near the crest of the second line of dunes. Olson was able to show that a vegetation cover of Ammophila breviligulata raised the level of calm air near the surface thirty times higher than when the surface was bare.

Thus, at Kaitorete, although the covering of Desmoschoenus on the fore dunes is only low, and not particularly dense, it can be appreciated that it must play a very significant role in reducing the erosive force of wind, while the absence of vegetation on the blowouts leaves the force of the wind unchecked. Further inland, the force of the wind will be checked much more efficiently by the indigenous tussock-shrub vegetation than by the sparse, low-growing adventive annuals which have invaded severely disturbed areas.

(d) EVAPORATION

To obtain comparative figures for the evaporative power of the air at different stations from spring through to the driest months in late summer, evaporimeters were installed at stations A, B, C and D, and read at approximately fortnightly intervals from 7 September, 1971 to 12 March, 1972.

The type of instrument used was an atmometer. A porous porcelain cup was attached by a steel tube to the top of a firm plastic canister of 2 litre capacity, passing through the screw top. To the lower end of the short steel tube was attached a 17cm length of plastic tubing, the distal end of which was tied back to form a loop holding a few ml of mercury, to provide a valve which prevented entry of rain-water at the porous surface. Just below the neck of the can was a 2cm stoppered hole to permit additions of water and measurement of water loss.

Before installation, the four instruments were given a trial run in Christchurch, being exposed to hot windy conditions for 18 hours. Two which showed the same rate of evaporation were taken as the standard against which the other two were calibrated.

Some difficulties were experienced in the use of these instruments in the field. When first installed, they were set 12cm into the ground beside the marker stake at each station, the evaporating surface being 20-30cm above ground level. Cows or sheep appeared to be attracted by the moist surface and caused some interference, necessitating the erection of a barrier of wooden stakes around each instrument.

A more difficult problem was the blocking of the pores in the porous pot by wind-blown dust. This occurred several times at stations B and D, necessitating removal of the instruments, dismantling, cleaning, and rechecking their performance in Christchurch before returning them to the field, thus leaving gaps in the record on several occasions.

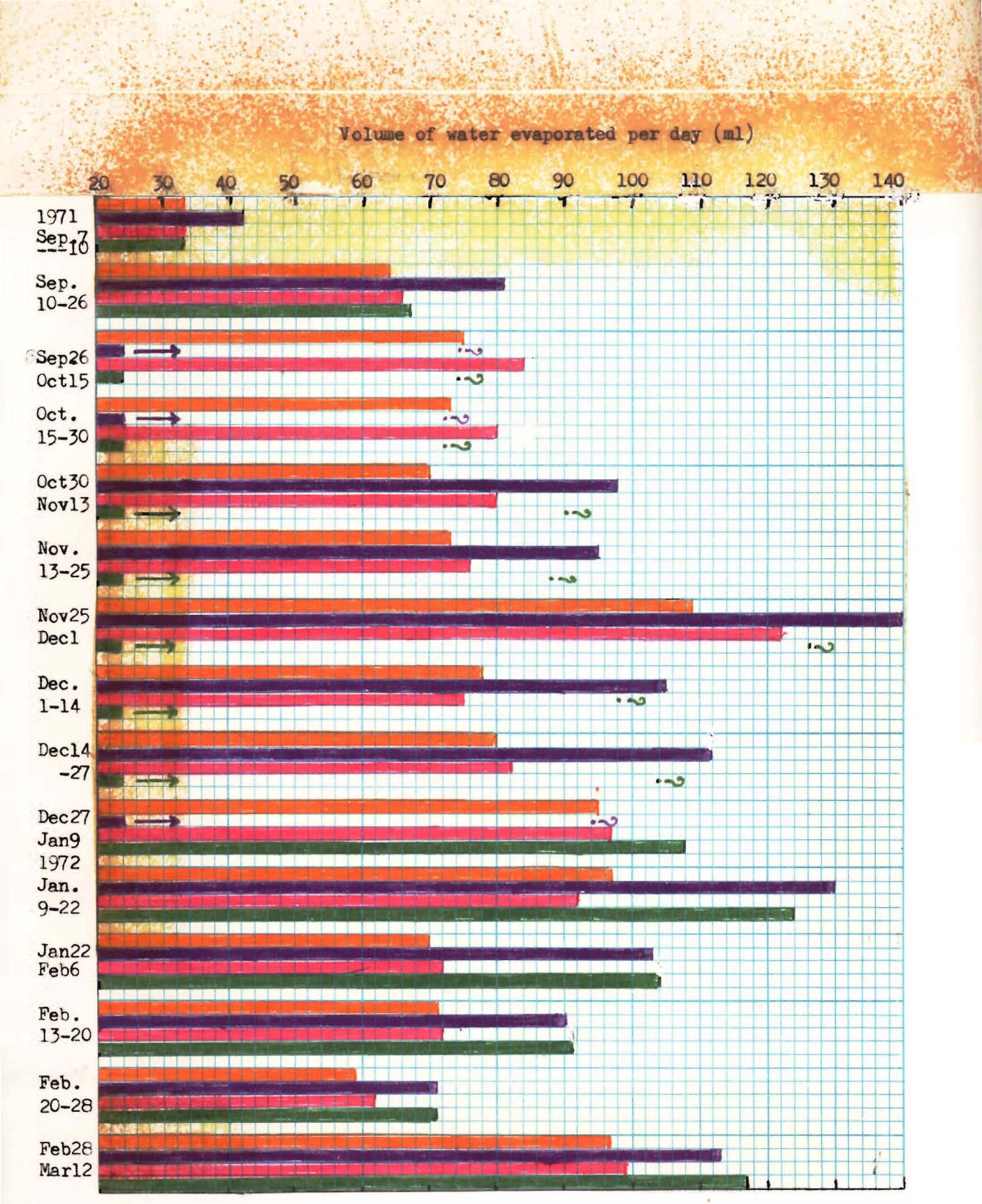


Fig. 31. Evaporation from evaporimeters at four microstations, Sep.1971– Mar.1972.

Mean daily volume calculated from total for each period measured.

(→? indicates instrument out of order).

Station A —— , B —— , C —— , D —— .

Lat. 43°39" S. Heat Index = 46.8

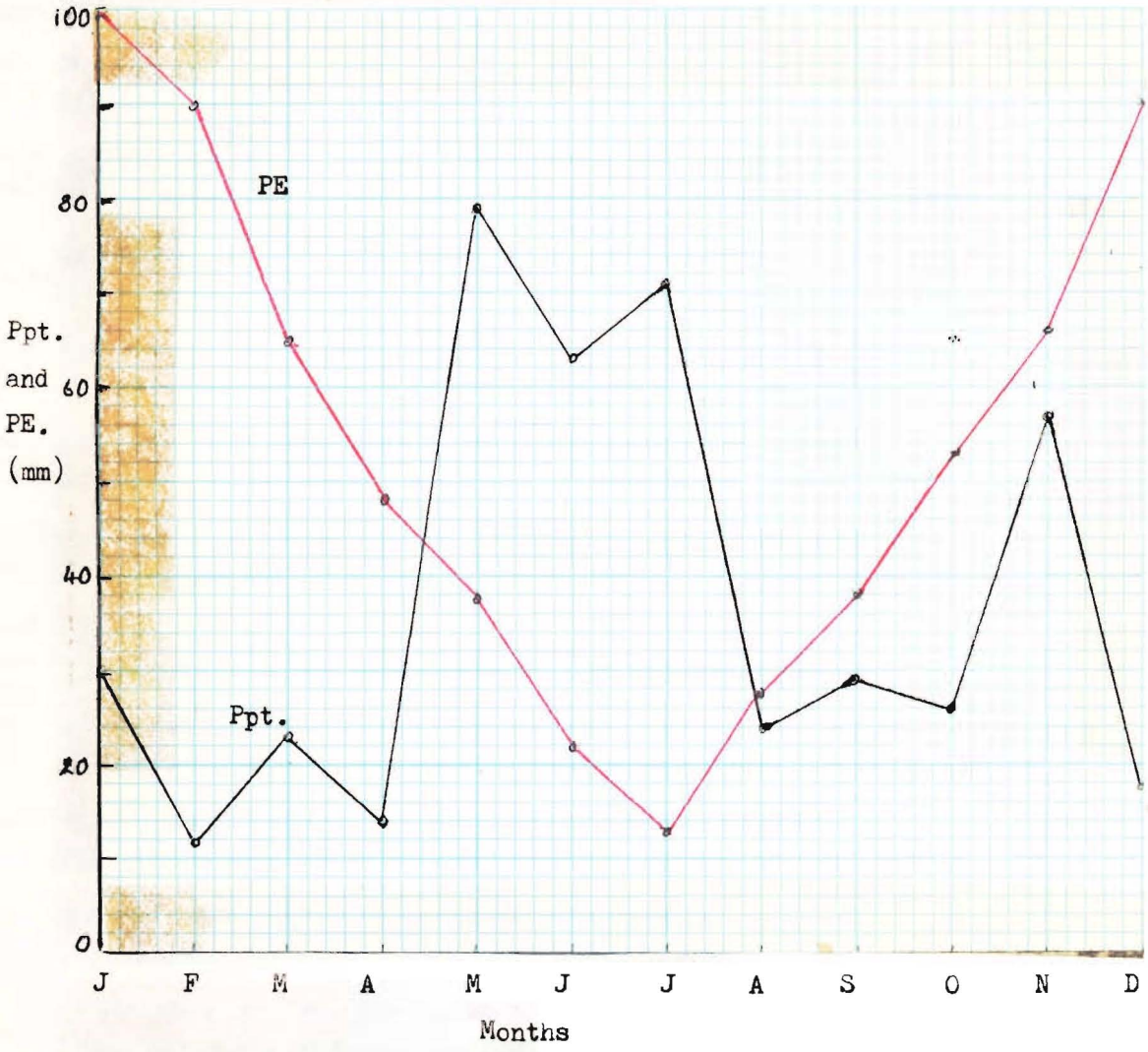


Fig. 32. Monthly precipitation and potential evapotranspiration, at Lincoln, 1971. PE calculated according to Thornethwaite.

	J	F	M	A	M	J	J	A	S	O	N	D	Total Ann.
Ppt.	30	11.8	22.8	14	79.3	63	71.4	24.1	29.1	26.3	56.9	17.6	446.3
PE	99	90.2	65.3	49.0	37.8	22.6	13.4	27.7	37.8	53.1	65.8	90.2	651.9
	-69	-78.4	-42.5	-35	-41.5	-30.4	-58.0	-3.6	-9.7	-26.8	-8.9	-72.6	-205.6
	D	D	D	D	R	R	R	D	D	D	D	D	D

D = depletion R = recharge

Results are summarised in Appendix II, Table 12, and Fig. 31. Appendix II, Table 13a gives figures for evaporation from a raised pan at Lincoln. Potential evaporation, compared with precipitation (calculated according to Thornethwaite, (1957) for each month of 1971 at Lincoln, is indicated in Fig. 32.

Discussion:

It is evident that high evaporation rates must prevail for most of the year, in view of the factors of temperature, humidity, and wind, already discussed. Fig. 32, based on Thornethwaite's method of calculating potential evapotranspiration, indicates that the amount of rainfall is exceeded by PE for all months of the year except May, June and July. Raised pan evaporation data from Lincoln (Appendix II, Table 13a) show a figure nearly twice that of calculated PE in 1971. This can be accounted for by the prevalence of hot, dry winds at Lincoln (the well known Canterbury "nor-wester") since Thornethwaite's formula is based on thermal index, and makes no allowance for unusually low humidity. However, it must also be remembered that PE is based on the assumption of adequate soil moisture at all times, which is certainly not the case at Lincoln. The evaporation data given for Lincoln provide some indication of the significance of this factor at the Spit, where even higher figures could be expected, from the greater amount of wind, although during dry periods actual losses from evapotranspiration would be much lower than the calculated PE.

From the evaporimeter data for the different stations (Fig. 31) it appears that the evaporative power of the air is much the same at B and D, being significantly higher at these sites than at A and C. This is presumably explained by the absence of sheltering vegetation on the blowout and on the sandy flat. The lowest rate of evaporation, shown at A, is apparently due to the cooler temperatures and higher humidity prevailing on the foredune.

Oosting (1942) obtained quite different results, reporting highest evaporation rate on the foredune, next highest on the rear dune, and lowest on the interdune flat. It would, therefore, appear that local factors, such as

amount and type of vegetation, direction of prevailing wind, and nature of the substrate are important in determining relative evaporation rates.)

(e) SUNSHINE

Reference to this factor is relevant at this point, although no measurements were made at the Spit, since it was considered that the amount of sunshine received there would be virtually the same as at Lincoln.

Monthly totals recorded there in 1971 are shown in Appendix II, Table 13b, the annual total being 1955 hours (about 5% higher than the figure recorded for Christchurch Airport, a little further inland). Sunshine recorded for 1971 was somewhat lower than the average figure of 2053 hours over the period 1967-1971 at Lincoln, this being slightly over 45% of the possible total. (See also sunshine data in Appendix II, Tables 14 and 15).

Discussion:

It can be seen that sunshine values alone do not give a true impression of the evaporative power of the air in the Christchurch region, where very low humidities can be caused by the warm, dry nor-west winds, even on days of partial cloud.

OBSERVATIONS ABOUT THE CLIMATE IN GENERAL

The microclimate of the Spit reflects the climatic characteristics of the whole region of lowland coastal Canterbury. The information given below has been taken from de Lisle (1969) and Garnier (1958) and N.Z. Meteorological Service climatological tables for Lincoln and Christchurch, as reproduced in Appendix II, Tables 14, 15, 16, 17, 18.

The climate of the region can be summed up as sub-humid and microthermal. Geographical and topographical features combine to cause low rainfall and hot dry winds from the north-west.

Annual rainfall is highly variable, and in such a low rainfall area even a small drop below the average can have severe effects on the vegetation. The mean annual precipitation for Christchurch (over a 15-year period) is 731mm, but it is important to note that within this period are some years of extremes which take the climate into the humid or dry subhumid categories.

Mean monthly relative humidity (measured at 9.30 a.m., over a period of 60 years) is regularly below 70% during October, November, December, January and February. Extremes of low RH, less than 20%, were recorded seven times over the period 1938-1948.

The greater part of the region's precipitation is derived from cold fronts advancing from S or SE and these periodic invasions of subantarctic air can cause a sudden extreme drop in temperature at any season of the year. The temperature may fall as much as 12^{o}C within 2 hours. Ground frosts frequently occur more than 100 times per annum, a higher figure than for any other region in New Zealand except for inland and upland South Island. There is a wide range in seasonal temperature extremes. Means taken over an 88 year period show that temperatures

regularly rise above 26°C during November, December, January, February and March, and fall below 0°C during May, June, July, August and September.

It can certainly be said that variability is the main characteristic of the day to day weather and of the seasonal and year to year climate.

Fig. 33. Carmichaelia appressa at station E in August 1972, showing branches chewed and torn off by cattle.

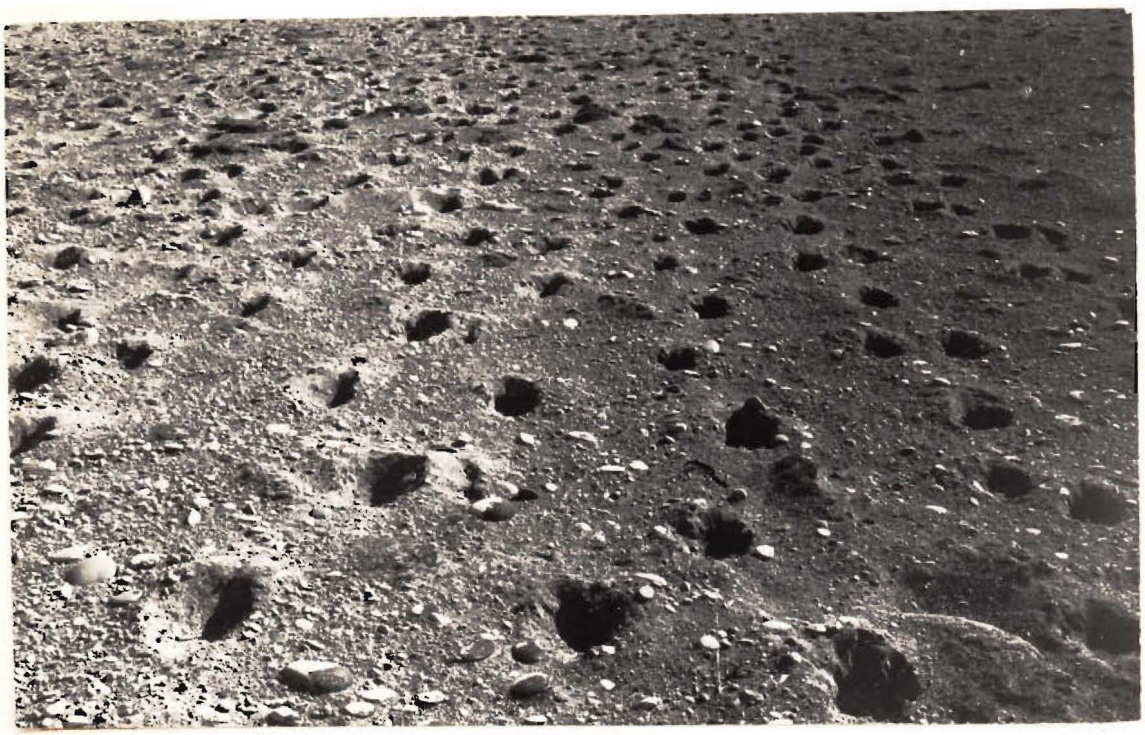


Fig. 34. Hoof prints of cattle on blowout.

4. INFLUENCE OF ANIMALS

The effects of grazing on the dune vegetation were dealt with at some length by Wraight (1957), and no systematic investigations were made of biotic factors in the present study.

However, subjective observations were made throughout the year on the activities of domestic stock, hares and rabbits, and their effects on the vegetation.

On Birdling's property, heaviest stocking occurs from mid-winter to spring. From early spring to mid-summer there are 2000 ewes with lambs; in addition, from April to July there are 30 heifers, and from July to September up to 100 cows with calves. During the rest of the year, smaller numbers of sheep and no cattle are present.

Wraight (1957) has given some indication of how grazing has affected the vegetation, and following are personal observations. Palatable herbaceous indigenes (such as Vittadinia australis and Rhagodia triandra) are scarce and tend to be confined to the shelter of shrubs. Palatable adventive species are also kept close-cropped. Shrubs in the old dune area are undoubtedly kept lower than normal by browsing, which is also likely to prevent-seedling establishment. The effects of cattle are far more drastic than those of sheep. Tussocks of Poa laevis and whole plants of Stipa are commonly uprooted and left lying, presumably rejected after the cattle eat more palatable species in their shelter. Destruction to Carmichaelia appressa is particularly severe, whole branches up to one metre long frequently being torn off a plant, and terminal branches macerated by chewing of cattle (Fig. 33). Desmoschoenus is frequently uprooted by cattle, although they do not seem to eat it; this is particularly noticeable on the unfenced, compared with the fenced, side of dunes on Mr Bayley's property.

Trampling of cattle causes considerable sand disturbance on the younger dunes and blowouts, where destruction of plants is significant. Fig. 34 illustrates

Fig. 35. Carmichaelia appressa damaged by hares at stationE.

Fig. 36. Raoulia australis damaged by rabbit burrowing at station D.

the effect of six cows having walked across the blowout, making hoofprints up to 13cm deep. Following the trail of one animal revealed that on the average every sixth hoofprint caused partial or complete destruction of a plant (generally Raoulia or Scleranthus) which would have taken several years to grow - apart from the obliteration of less conspicuous small seedlings. The trampling of sheep is much less damaging.

Hares are abundant, especially amongst the Desmoschoenus of the dunes, where two or three were seen within the limits of the study area at each visit.

Rabbits occur in large numbers, especially on the sandy flats and short grassland, where scores can be seen at night.

Shooting is not permissable except by officers of the Pest Destruction Board, who make occasional visits.

Rabbits and hares are doubtless responsible for nibbling young shoots and seedlings of many species. Most noticeable is the effect of hares biting off the young leaves of Desmoschoenus. On several occasions fresh hare tracks were noticed just above the strand-line, showing that a hare hadmoved from one Desmoschoenus seedling to another to feed, while ignoring seedlings of Ammophila of the same size. Hares also seem to be largely responsible for biting off inflorescences of Acaena ovina and its hybrids (the more prickly heads of Acaena novae-zelandiae are left untouched). Carmichaelia shoots are severely attacked by hares, and probably also by rabbits (Fig. 35).

Rabbit burrowing causes damage by loosening the surface and undermining plants, more especially in the old dune area (Fig. 36), but also to a lesser extent on the seaward slopes of the rear dunes, where these are covered by moss and Rumex acetosella.

In March, 1971, an area measuring three metres square, at E, was enclosed by stakes and wire netting one metre high, to observe the effect of removing the browsing factor. Although this remained in place for just over a

year, and was effective in keeping animals out, growth of most species during that time was so slight that the enclosed vegetation appeared very little different from its surroundings. The only striking result was the greater growth in spring of Acaena ovina, which was able to produce untouched inflorescences up to 50cm high, in contrast to the plants outside, whose flower buds were generally bitten off by hares.

The insect population is a special feature beyond the scope of this study. In passing, reference can be made to the enormous numbers of small moths which emerged from the foliage at dusk; caterpillars of these presumably must be an important factor. Small grey-green caterpillars almost defoliated plants of kowhai and lupin in the summer.

Fig. 37. Top of the foredune, near station A, looking southward; mainly *Desmoschoenus spiralis*; a patch of *Carmichaelia appressa* and *Lagurus ovatus* Aat lower left.

Fig. 38. View of the blowout, station B, lookingg N-NE. Longitudinal dunes in background. *Raculia* mounds damaged by SW wind from left.

Fig. 39. View of rear dune from the north side.Sandy flat,stationD, in foreground.Muehlenbeckia complexa,Desmoschoenus spiralis on the dune;Lagurus ovatus, Trifolium arvense and Raoulia australis on the flat,with Poa laevis in foreground.

Fig. 40. Vegetation of the old dune community,near station E.Poa laevis and Carmichaelia appressa.

CHAPTER FOUR

THE VEGETATION

In this chapter are described methods of studying the vegetation, together with results and observations. Discussion is reserved for the following chapter, in which plant attributes are linked with environmental influences.

General accounts of the flora and vegetation of the Spit have previously been recorded by Wall (1930, Burrows (1969a and b), and a more detailed account appears in Wraight (1957). In the present study nomenclature follows Allan (1961) for indigenous dicotyledons; Moore and Edgar (1972) for indigenous monocotyledons except grasses; Zotov (1963) for indigenous grasses; Healy (1969) for adventive species. A list of species mentioned in the text appears in Appendix III.

1(a) GENERAL DESCRIPTION

In the following description attention is mainly confined to the vegetation of the study area, although passing reference is made to other areas which are notably different. The relationship between landforms and broad vegetational units, and location of microstations can be seen from Figs 3, 4, 5; Figs 37, 38, 39, 40, show general views of these stations.

At A the seaward slopes, top, and lee slopes of the foredune are well covered with Desmoschoenus spiralis; there are scattered plants of Hypochaeris radicata, (catsear), Calystegia soldanella, (sand convolvulus), Lagurus ovatus, (harestail grass), and Rumex acetosella, (sorrel), with rare patches of Carmichaelia appressa, (prostrate broom) (Fig. 41).

At B the sandy surface is thickly strewn with smooth, rounded stones up to 8cm in diameter, many of them partially or completely encrusted with a black species of Parmelia, suggesting that the area has existed in its present state

Fig.41. Vegetation at station A: Desmoschoenus, Lagurus Hypochaeris.

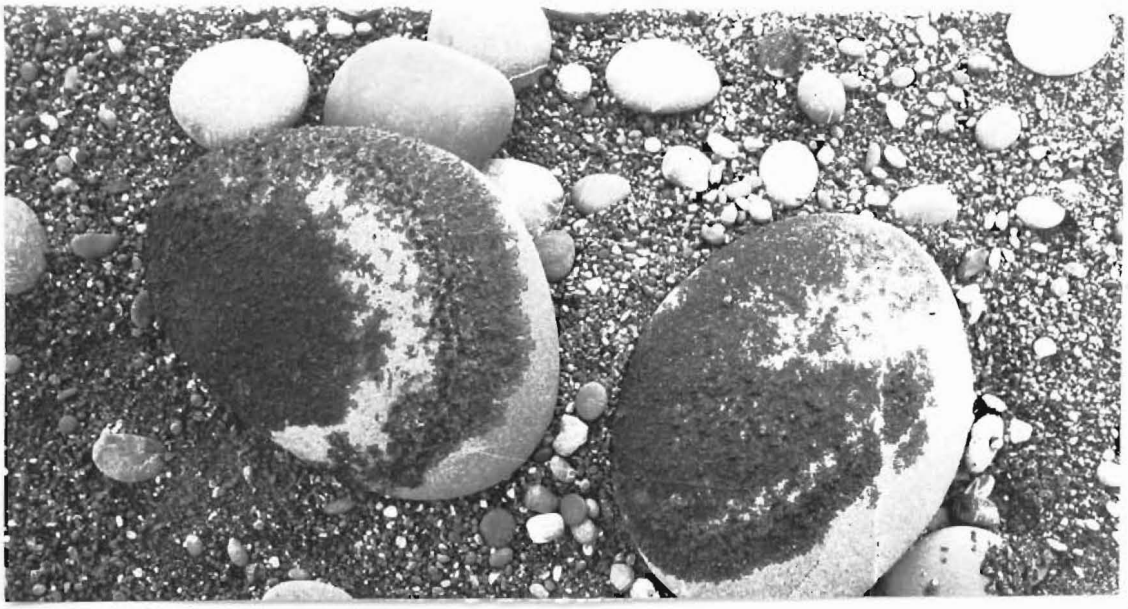


Fig. 42. Very coarse sand and gravel on the suface at station B.
Many stones covered with the lichen Parmelia plivacea.

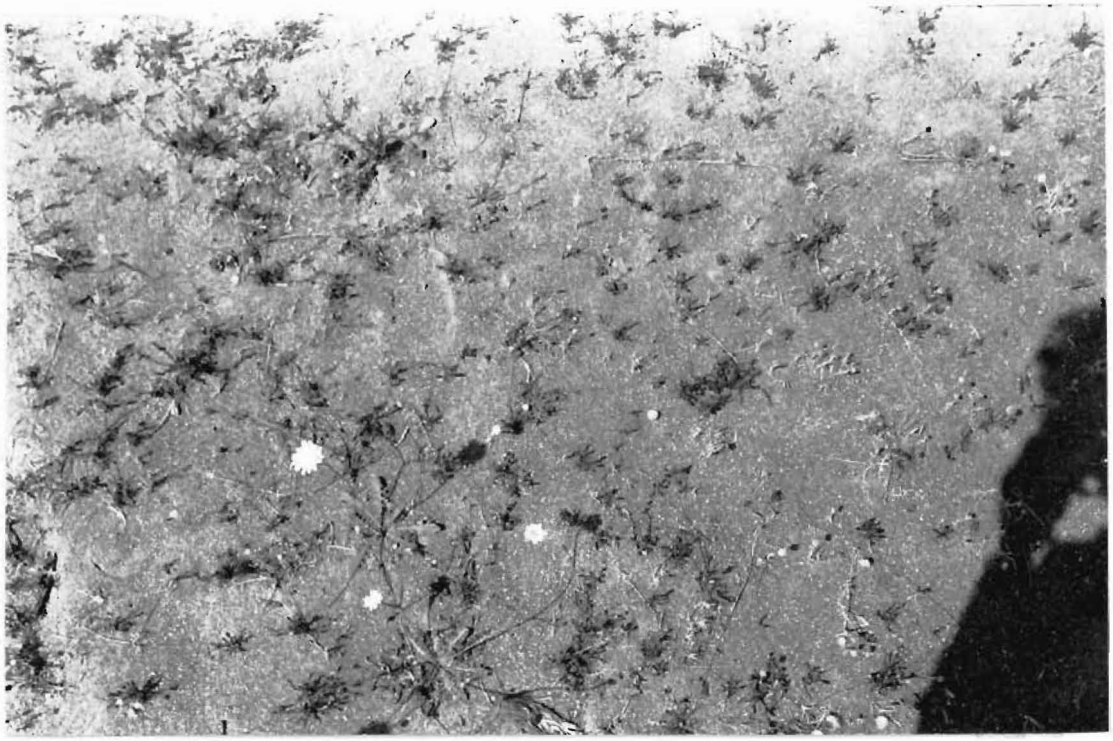


Fig. 43. Vegetation at C, south slope: Hypocchaeris, Lagurus, Rumex acetosella.

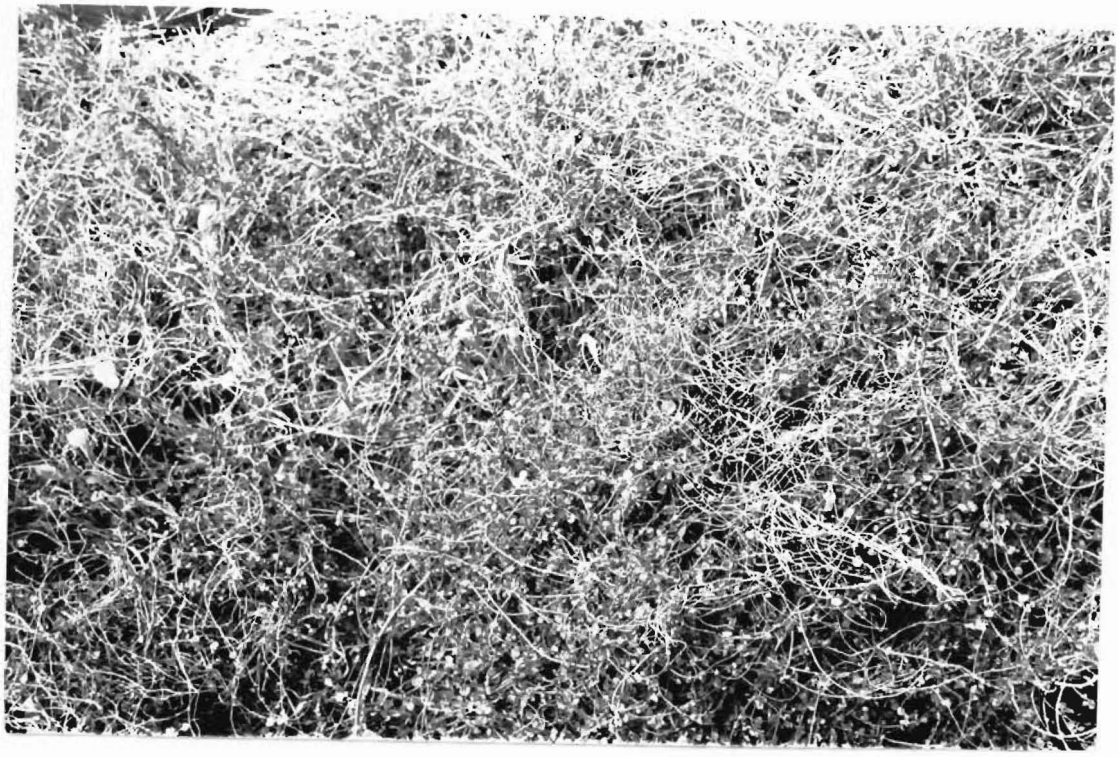


Fig. 44. Vegetation at C, north slope: Festuca ovina complex, Brachypodium pinnatum.

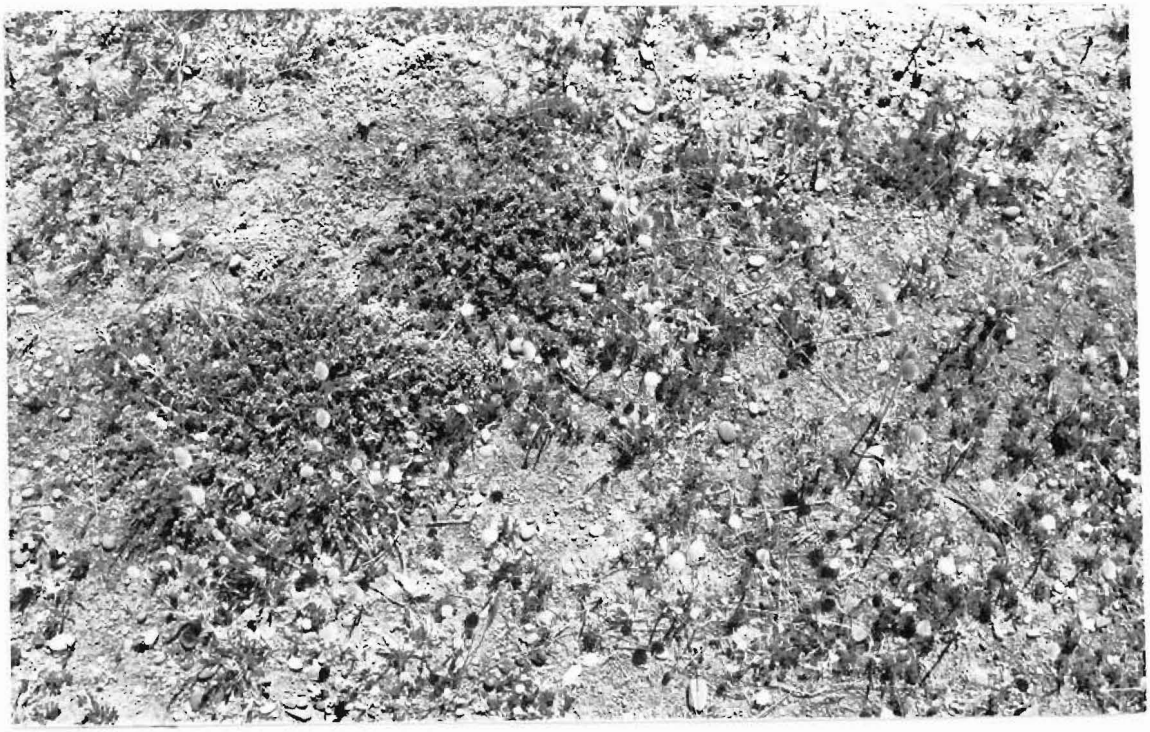


Fig. 45. Vegetation at D:Pimelea prostrata,Trifolium arvense, Lagurus.

Fig. 46. Vegetation at D:Raoulia australis, Trifolium arvense,Stipa variabilis,Notodanthonia unarede, Lagurus.

for some considerable time (Fig. 42). The vegetation here is very sparse, consisting mainly of mats or mounds of Raoulia australis (for more details of this plant form, see Section 5). Scleranthus uniflorus, Pimelea prostrata, (N.Z. daphne), Hypochaeris, Rumex and Lagurus occur rarely. A few seedlings of Desmoschoenus (much chewed by hares) are present, while a few older plants are fixing small mounds of sand which could form the nuclei of future dunes. Zoysia minima (pygmy twitch) is important as a sand binding grass; Carex pumila (sand sedge) is not present here, but occurs in the adjacent blowout. Near the bases of the dunes, Bromus diandrus (barren brome) and isolated tussocks of Poa laevis (silver tussock) occur, but they are more frequent in the vicinity of the rear dune.

At C much of the dune ridge and the northern slope are covered by Muehlenbeckia complexa clumps, up to one metre high and several metres across. Carmichaelia appressa is abundant, growing either prostrate or, if associated with Muehlenbeckia, producing vertical shoots up to one metre high. On the more open parts there are scattered plants of pingao, convolvulus, catsear and sorrel (Fig. 43). Craspedia lanata (woollyhead) is not uncommon. Rhagodia triandra, Lagurus and Bromus diandrus grow in close association with the shrubs (Fig. 44).

At D, on the sandy flat, the vegetation is sparse, though more in evidence than at B. Catsear and sorrel are common; also the perennial grasses, Stipa variabilis (needle grass) and Notodanthonia unarede. Between June and January the area is dominated by the annuals, Lagurus and Trifolium arvense (haresfoot trefoil), together with a little Bromus diandrus. The perennials, Raoulia, Scleranthus, Poa laevis and Pimelea are found occasionally (Figs 45, 46).

At E the plant community has been longest established. It is dominated by clumps of Carmichaelia appressa and tussocks of Poa laevis (some growing up to 70cm high, but many in a moribund state). Notodanthonia and Stipa are common; other grasses present are Anthoxanthum odoratum, Poa pratensis and Lolium perenne, which are so much sought after by grazing animals that they generally survive only

Fig. 47. Vegetation at S :Fes laevis,Aegeno ovina,Lagurus,ovatus,
Ery lamellis silvosa.

Fig. 48. Vegetation at S: Lagurus, Aegeno ovina,Anthoxanthum
odoratus,Briza media

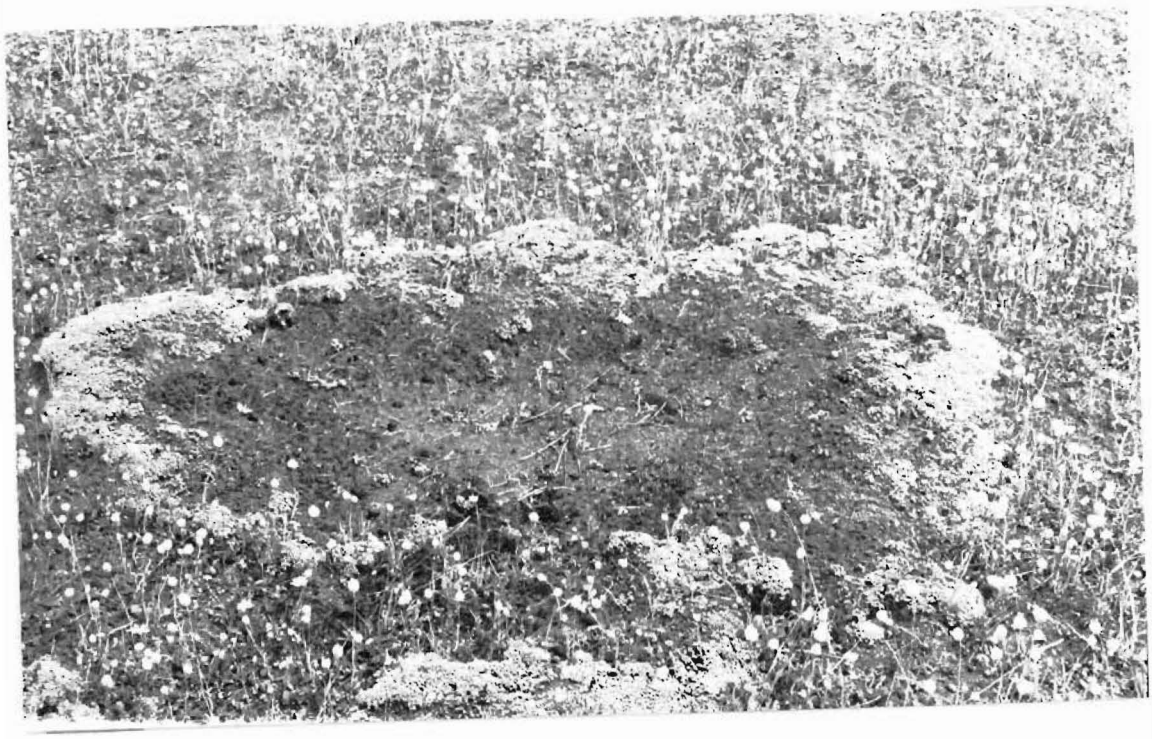


Fig. 49. Old Maculia plant, one metre in diameter, at a much-modified site in the old dune area; note that centre is completely dead, while growth continues at the periphery.

Fig. 50. Much-modified old dune area, looking east from near boundary at western end of Birding's property; Lagunaria patersonia is the dominant species.

Fig.51. The lichen, *Parmelia conspersa* covers much of the ground surface in areas such as that shown in Fig.50.

Fig.52. Remains of woody plants lie scattered over parts of the old dune area.

Fig. 53. The old dune area. Truncated dune remnants covered with Muehlenbeckia, Desmoschoenus and Poa laevis.

Fig. 54. Looking south from old dune area towards rear dunes; Pteridium esculentum much in evidence.

in the shelter of tussocks or mats of Carmichaelia. In places there is a complete ground cover of the moss, Triquetrella papillata, interspersed with the perennial forbs Acaena ovina A. australis (bidi-bidi), and their hybrid forms, plus Hypochaeris, Rumex and Calystegia. In winter, the annuals, Silene gallica (catchfly) and Cerastium glomeratum (mouse-eared chickweed) are common (Figs 47, 48). Some open, sandy patches occur; on these are present old-established mats of Raoulia (moribund in the centre) and the annual grasses Lagurus and Aira caryophyllea (Fig. 49). Cyathodes fraseri, Carmichaelia corrugata, Dichondra repens, and Trifolium species occur rarely.

AREAS MARKEDLY DIFFERENT FROM THE MAIN STUDY SITE.

The area on the northern side of the main line of rear dunes is very variable along the Spit.

At the western end of Birdling's property there are extensive areas supporting little vegetation except a small grey-green lichen Parmelia conspersa, the drought-resistant moss Triquetrella papillata, and the summer annual grass Lagurus (Figs 50, 51). Small areas of the above description occur also immediately to the west of the study site, and in places remnants of quite thick woody branches lie scattered on the sandy surface (Fig. 52). However, this area also has densely vegetated old dune hummocks, rising one to two metres above the general level, covered with Pteridium esculentum (bracken), Carmichaelia appressa, Poa laevis and Desmoschoenus (Fig. 53). Pteridium also commonly forms extensive patches on the flats and on some of the rear dunes, but it is generally less than 45cm in height and often appears moribund (Fig. 54). Small bushes of Hymenanthera alpina and Muehlenbeckia complexa commonly occur, their branches often covered with the lichens Ramalina and Teloschistes, and there are rare specimens of Clematis afoliata and Lupinus arboreus. On Bayley's property, the tussock-shrub community has been entirely replaced by adventive grasses and forbs, with a fair amount of Raoulia and bare sand.

Fig. 55. Myoporum laetum on foredune 4m west of study site. Scattered dead branches show that this was once a large tree;now only low shrubby growth remains,sprouting from buried branches.

Fig. 56. Myoporum laetum on rear dune near Birdling's western boundary.

Fig. 57. Myoporum laetum on foreshore opposite Bayley's house; just above high-tide mark and subject to wave-erosion during SW storms.

Fig.58. Dodonea viscosa shrubs scattered over longitudinal dunes and dune hollows, 1 km west of study site.

(b) RELICT TREES AND SHRUBS.

A particularly interesting feature of the dune vegetation is the presence of a few small shrubs and trees which appear to be of relict status. I consider these important, as possibly indicative of what an earlier vegetation of the area may have been like. Since it is doubtful how long they may be able to continue their tenuous existence, they are described here in some detail.

Myoporum laetum (ngaio) occurs in three places. About 400m west of station A, on the crest of the foredune, there is the remnant of a tree which has had several trunks up to 14cm in diameter and probably up to 4 or 5m high; the side exposed to the south-west has progressively succumbed to the sand - and salt-laden winds, leaving a mass of dead branches; on the sheltered side, branches blown prostrate have taken root as they became buried by sand, producing the present appearance of a clump of shrubs 2-3m high (Fig.55). Another ngaio specimen occurs on the rear dune about 200m west of the Birdling-Bayley boundary fence; here there is a ring of shrubby plants around an open central space in which there are remnants of branches, suggesting that here again an old, large tree has been overwhelmed by sand (Fig.56). The third occurrence is on the foreshore nearly opposite Bayley's house, where two old trees are barely surviving on dunes which are being actively eroded away by the encroaching sea, (Fig.57). All the above specimens produce flowers and fruit, but no young plants are present.

Dodonoea viscosa (akeake) numbering about 30 plants occurs on a group of dunes about 1.5km east of the Birdling-Bayley boundary fence. They are scattered over dune ridges, leeward slopes, and the flat blowout area, the smallest being about 0.6 and the largest 2m high (Figs 58,59). All are strongly "wind-shorn", with branches on the seaward side denuded of leaves and often dead. Some have trunks up to 13cm in diameter, emerging from the dune almost horizontally, and terminal branches have taken root. One completely dead specimen had 5m of trunk (10cm diameter) lying on top of the sand, plus another 2m of the lower part buried and decaying

Fig.59. Dodonea viscosa showing effect of wind from the SW (left).

Fig. 60. Dodonea viscosa; partly buried remains of dead specimen, 5m tall.

Fig.61. Scaevola microphylla on rear dune near study site, showing effect of SW wind from water

Fig.62. Correasa propinqua: small tree forms growing on north side of rear dune near Bayley's house.

(Fig.60). Examination of a cross-section revealed very little sign of reaction wood (which is normally pronounced in horizontally inclined trunks of this species), suggesting that the specimen may have been considerably taller than anything growing on the dunes to-day. Although flowers and fruit are produced abundantly, no young seedlings were apparent. This occurrence of Dodonoea viscosa is interesting as the southernmost to be recorded in New Zealand (possibly in the world); it also occurs on Banks Peninsula.

Sophora microphylla (kowhai) is represented by two specimens, on the lee side of the inland dune, about 1km east of Station C. The larger one has multiple trunks, up to 9cm in diameter, strongly inclined to the north-east; the bushy top, reaching a height of 2m, is shorn flat as a table-top (Fig.61). A smaller specimen grows close by. Another specimen, mentioned by Wraight (1957) as being on the dunes opposite Bayley's house, was reported by Mr. Bayley to have died several years ago, probably from damage by cattle; examination of the trunk showed it to have been the same size as the tree described. The foliage of the kowhais was almost entirely devoured by caterpillars, probably contributing to their stunted growth and failure to flower.

Muehlenbeckia astoni (another example of southernmost distribution) occurs about 2km west of the quarry, as well as at Birdling's Flat.

Coprosma propinqua, though occurring on the gravel at Birdling's Flat, is found on the dunes in only one place, just to the east of Bayley's homestead. There are four plants of tree-like form, slightly over 2m in height (Fig.62).

Examination of growth rings in the wood of the ngaio, akeake and kowhai suggested that all the trees were about 60 years old, but they could be much older, since in this type of semi-arid habitat only one ring of new wood cells, or none at all, may be formed during a year.

2(a) SELECTION OF COMMUNITIES FOR STUDY.

Wraight (1957) referred to the distribution of plant associations on the Spit as occurring in definite bands, parallel with the shoreline. This is an over-simplification of the vegetation pattern, which is here studied in units related to topography as well as distance from the sea.

Many different approaches have been made to the concept and description of plant communities; various viewpoints are discussed by Whittaker (1962), and Daubenmire (1968). Braun-Blanquet (1932) placed emphasis on "fidelity of species" to define units which he considered to be discrete. Clements (1936) was much concerned with the idea of community succession. Poore (1956) described what he called "noda", i.e. commonly-occurring combinations of species, linked by intergradations, while Whittaker and also Goodall (1953) incline to the view that vegetation is best regarded as a continuum.

The present study adopts Poore's concept of noda linked by intergrades as a basis for the consideration of the patterns of vegetation on the Spit, but does not adhere to his methodology. The floristic analysis is approached differently, and no attempt is made to analyse the complete pattern of nodes and intergrades.

The five sites at A, B, C, D and E were selected because each appeared to represent a type of plant community significantly related to a particular set of environmental factors of a clear-cut nature, e.g. topography and distance from the sea. Vegetation analysis was carried out within a radius of 50m from each station marker. This size restriction was necessary to ensure that each stand was reasonably homogeneous and distinctive; extending these boundaries would have meant including transitional areas such as the damper spots at the base of dunes or patches impoverished by recent fires.

2(b) VEGETATION ANALYSIS.

Quantitative information about the botanical composition of the selected communities was required to assist the study of seasonal changes.

In deciding upon the most appropriate method of sampling, the following points had to be considered:

(i) The chief requirement was an accurate picture of percentage ground cover for each species, together with the percentage of bare ground and litter. Height measurements were less important, since the majority of species were low-growing herbs; the significance of the few taller species could readily be indicated by photographs.

(ii) The method needed to be rapid enough for two operators to be able to sample all five communities reasonably adequately in a single day.

(iii) Minimal interference with the natural state of the vegetation was desirable, since sampling was to be repeated at intervals through the year.

Point analysis, based on the method described by Radcliffe and Mountier (1964) was used in preference to quadrat methods (Grieg-Smith, 1957).

To provide a representative and relatively unbiassed sampling of each community, and also to enable subsequent resampling of the same area, a compromise was made between subjective and objective placing of the points by using fixed transects in conjunction with a frame of needles. Because of the limited size of each community, and to ensure an even coverage of the slopes and ridges of the dunes, transects were pegged out in a radial pattern, starting 3m out from the central marker stake of each station (to avoid excessive trampling in this area), and extending for 20m in north, south, east and west directions. Along each of these transects 100 points were taken, by 20 placings of a frame of 5 needles spaced 5cm apart, and placed vertically allowing one length of the frame between successive placings. Thus 400 points were taken at each station (see note later).

The use of a point analysis frame is most suitable for pasture conditions, and less so for vegetation of varying heig but proved generally adequate for the study area. Adjustments to the length of the end supports allowed for clearance of all but the tallest species encountered, Muehlenbeckia; for large clumps of this species, it was not possible to place the frame precisely and some estimation by eye was necessary.

In point analysis it is usual to record for each species either first hits (cover hits) or total hits, the former giving a cover value and the latter a measure of density. In the communities represented here, cover repetitio rarely occurred, except for Poa laevis, Muehlenbeckia, and, to a lesser extent, Desmoschoenus, so only first hits were recorded. It must be kept in mind that each of the above-mentioned species was actually represented, at each point where it occurred, by many layers of leaves and stems, but measurement of total hits would have been virtually impossible. For other species, however, total hits could be equated with first hits.

An inherent fault of point analysis is that species with flat, horizontal leaves and stems tend to be hit more often than species with narrow, vertical leaves and stems, thus the analysis may, for example, under-represent grasses compared with broad-leaved rosette plants.

In order to establish a suitable minimum number of points for each community, a preliminary analysis was made at station E in March, 1971, using 6 transects, each with 100 points. Calculations were made to show percentage cover for each species, (a) for 400 points, and (b) for 600 points. Comparison revealed that for most species the difference between (a) and (b) was less than 1% and in no instances more than 2%. Another trial run was made at station B, comparing results from (a) 400 points, and (b) 800 points; again the difference between percentages for any one species was generally less than 1% and not more than 2%. It was, therefore, considered that the extra time involved in taking more than 400 points would not be justified.

Table 2. Seasonal changes in percentage cover, old dunes, E.

Date:	12-4-71 Autumn	20-6-71 Winter	5-9-71 Spring	20-11-71 Summer	16-2-72 Summer	2-6-72 Winter	9-7-72 Winter
Species							
Aira caryophyllea	0	0	0	1.0	3.7	0	0
Anthoxanthum odoratum	0	2.7	4.0	1.2	5.0	4.2	3.2
Lagurus ovatus	0	6.5	7.2	5.0	0	5.0	7.0
Lolium perenne	2.2	7.0	6.2	3.0	3.2	4.5	5.5
Notodanthon. unarede	3.7	2.7	3.2	5.7	5.2	3.7	4.7
Poa laevis	14.7	16.5	17.2	15.7	14.0	16.0	14.5
Poa pratensis	0	1.0	1.0	0.2	0.2	1.2	2.0
Stipa variabilis	0.7	0.5	0.7	1.5	1.0	1.2	2.0
Bromus diandrus	0	6.2	8.2	6.0	0	5.2	5.0
Acaena ovina	6.0	21.0	20.0	9.7	10.7	10.7	15.0
Calystegia soldanella	0	0	0	0.2	1.0	0	0
Carmichaelia appressa	22.2	23.2	24.2	23.2	26.5	27.7	27.0
Cerastium glomeratum	0	1.5	1.2	0.7	0	1.7	2.2
Hypochaeris radicata	2.7	4.5	4.2	4.2	1.7	2.2	4.2
Triquetrella papillata	42.2	38.5	37.5	40.2	28.5	30.0	44.5
Rumex acetosella	2.7	9.0	8.5	6.5	6.5	10.0	11.5
Silene gallica	0	2.0	3.0	0.7	0	1.7	2.2
Trifolium arvense	0	1.2	1.5	1.2	0.7	1.0	0.5
Bare Surface	5.2	2.2	1.5	1.2	0.7	2.2	1.7
Litter only	27.7	20.0	15.7	18.5	32.2	21.7	16.5
Total hits per 400 points	525	679	654	588	573	612	687

Table 3. Seasonal changes in percentage cover, sandy flat, D.

te:	12-4-71	20-6-71	5-9-71	20-11-71	16-2-72	9-7-72
	Autumn	Winter	Spring	Summer	Summer	Winter
Species						
Lagurus ovatus	0	10.0	10.0	9.7	0	7.0
Notodanthon. unarede	4.2	3.7	4.0	3.2	3.7	3.7
Stipa variabilis	4.0	4.5	4.7	5.2	4.5	5.7
Bromus diandrus	0	0.2	0.5	0.2	0	0
Acaena ovina	0.7	0.5	1.5	0.2	0.5	0.5
Hypochaeris radicata	1.7	0.7	1.0	1.7	1.0	1.2
Pimelea prostrata	0.5	1.0	0.7	1.0	1.5	2.0
Raoulia australis	13.2	13.0	11.0	9.5	11.2	9.7
Rumex acetosella	1.5	4.2	5.5	3.0	1.5	4.7
Scleranthus uniflorus	0.2	0	0.2	0.2	0.7	0.4
Trifolium arvense	0	16.0	15.2	21.7	20.7	14.0
Bare surface	48.5	34.7	36.0	33.5	26.2	29.5
Litter	27.0	16.7	20.0	14.2	34.5	31.7
Total hits per400points	407	422	442	408	423	442

Species occurring too rarely to be recorded are listed below:

Stn E

Acaena novaezelandiae
Bromus mollis
Carmichaelia corrugata
Convolvulus erubescens
Dichondra repens
Hypnum cupressiforme
Hymenantheraalpina
Pteridium esculentum
Raoulia australis

Stn D

Carex breviculmis
Carmichaelia appressa
C. corrugata
Calystegia soldanella
Cyathodes fraseri
Gnaphalium luteoalbum
Poa laevis

Table 4. Seasonal changes in percentage cover, rear dune, C.

Date:	12-4-71.	20-6-71.	5-9-71,	20-11-71.	9-7-72,
	Autumn	Winter	Spring	Summer	Winter
Species					
Lagurus ovatus	0	10.2	12.0	7.5	2.7
Bromus diandrus	0	3.7	5.2	4.7	3.2
Desmoschoenus spiralis	3.7	3.5	4.0	4.7	6.2
Calystegia soldanella	0	0	0	0.2	0
Carmichaelia appressa	5.2	4.0	4.7	7.0	7.5
Hypochaeris radicata	1.5	1.7	2.2	2.0	1.0
Triquetrella papillata	0	0.7	1.7	0.7	2.5
Muehlenbeckia complexa	40.2	37.5	38.0	36.5	31.2
Rhagodia triandra	0.2	0.7	1.5	0.2	0.5
Rumex acetosella	2.7	6.5	5.7	6.5	6.2
Bare surface	35.2	31.7	29.5	32.7	45.2
Litter	12.7	7.5	5.2	9.5	7.2
Total hits per 400 points	407	432	432	448	455

Species occurring too rarely to be recorded:

Stn C

Craspedia lanata

Silene gallica

Table 5 a. Seasonal changes in percentage cover, blowout, B.

Date:	12-4-71. Autumn	20-6-71. Winter	5-9-71. Spring	20-11-71. Summer	9-7-72. Winter
Species					
Lagurus ovatus	0	0.2	0.5	0	0.7
Zoysia minima	1.0	1.3	1.5	2.4	2.0
Desmoschoenus spiralis	0.2	0	0	0	0.2
Hypochaeris radicata	0	0.2	0.5	0	0.2
Raoulia australis	3.7	3.0	3.2	4.0	3.7
Rumex acetosella	0	0.2	1.0	0.2	0.6
Scleranthus uniflorus	0.5	0.2	1.2	0.5	0.7
Bare surface	87.7	88.3	85.7	86.2	85.4
Total hits per 400 points	400	400	400	400	400

Table 5 b. Seasonal changes in percentage cover, fore dune, A.

Date:	12-4-71 Autumn	20-6-71 Winter	5-9-71 Spring	20-11-71 Summer	9-7-72 Winter
Species					
Lagurus ovatus	0	12	10	7.5	3.0
Desmoschoenus spiralis	18.5	22.2	22.5	23.7	26.7
Calystegia soldanella	0.7	0	0	2.2	0
Carmichaelia appressa	0	0.5	0.2	0.7	1.2
Hypochaeris radicata	5.7	6.0	3.7	3.2	5.2
Rumex acetosella	0	0.7	1.2	1.2	1.5
Bare surface	57.2	53.2	48.0	49.5	51.5
Litter	21.5	19.7	17.0	13.7	23.0
Total hits per 400 points	416	458	411	408	449

Species occurring in Stn B too rarely to be recorded:
Craspedia lanata Pimelea prostrata Bromus diandrus

To check whether the five stations marked for study did in fact represent fairly typical communities, vegetation analysis was carried out at 5 additional areas which showed comparable site characteristics, about 200m west along the Spit, i.e. station F - fore dune, station G - blowout, station H - rear dune, Station I - sandy flat, station J - old dune. On equivalent sites the same species were found to occur, although showing a certain amount of variation in percentage cover (Appendix III, Table 1).

Site F was very similar to A, except for a somewhat less dense cover of Desmoschoenus. Site G showed no significant differences compared with site B. Site H was comparable with site C, except that there was only one third as much Muehlenbeckia, and consequently less Bromus diandrus (generally growing in the shelter of the former), three times as much Desmoschoenus, and more bare ground. Site I was fairly similar to site D, except for the presence of Zoysia minima, and rather less Trifolium arvense. Site J was more open than site E, with virtually no stratification; only half as much Poa laevis, a quarter as much Carmichaelia appressa, half as much Acaena ovina, a third as much moss, ten times as much Stipa variabilis, and much more bare ground. The greater variation between this last pair of sites is readily understandable when it is remembered that station E was deliberately selected as being an example of the least disturbed vegetation on that type of site, and those further west appeared to be impoverished by fires.

In order to check seasonal changes in the vegetation, analyses were made at all stations on the following dates:

12 April,	1971	(autumn)
20 June,	1971	(mid-winter)
5 September,	1971	(Spring)
20 November,	1971	(early summer)
16 February,	1972	(late summer)

Two further analyses were made, on 2 June, 1972 and 9 July, 1972, to obtain a comparison with 1971 results.

Tables 2,3,4 and 5 show how the percentage cover of

each species varied throughout the year in each community. Section 2C following is derived from the information provided by these analyses.

2(c) FLORA AND VEGETATION OF THE SELECTED COMMUNITIES, INDICATING SEASONAL CHANGES.

Note: Species are dealt with in alphabetical order, grasses preceding forbs and other forms. The community at E is described first, since it includes many species found in other communities, thus reducing the need for repetition of description.

Old Dune Community, Station E.

(1) Aira caryophyllea, which is confined to this type of site, started germinating in late September; flowering occurred throughout November, December and January, the leaves (always very sparse) often withering before the inflorescence was fully developed. All plants were dead by the end of January.

(2) Anthoxanthum odoratum is also confined to this type of site, where it survives severe grazing only by growing in the shelter of Poa clumps and dense Carmichaelia. It is present in variable, low percentages throughout the year; the spring growth is largely removed by grazing, so that it does not show much increase in cover value.

(3) Bromus mollis, confined to this type of site, is present so rarely as to be scarcely noticeable except briefly during the early summer flowering period.

(4) Bromus diandrus occurs in small numbers, germinating in May, and reaching a peak of vegetative growth in mid-winter. (Much less growth was noticeable in the cold winter of 1972 than in the milder winter of 1971). It flowers in November, the leaves often withering before the inflorescence is mature and the plants are dead by January unless the summer is unusually wet.

(5) Lagurus ovatus occurs fairly abundantly in all the communities described (except for the blow-out area). On this site it is chiefly confined to the more open sandy patches. It germinates early in May and reaches a peak of vegetative growth in mid-winter (July) if temperatures are not too severe, otherwise in early spring. It flowers during

November and December, and at this time vegetative growth ceases; if competition for water is intense, owing to density of the species population, the leaves wither before the inflorescences are mature. The plants are dead by the end of December, although the flower stalks may remain erect with the heads attached until the following spring.

(6) Lolium perenne, confined to this type of community, is present in small amounts throughout the year, being more obvious when moist conditions of winter and early spring permit growth; it is much depleted by grazing, and leaves wither in the summer drought; only very occasionally do protected plants produce inflorescences in spring.

(7) Notodanthonia unarede is present at much the same low percentage throughout the year. Increased growth in spring and early summer is reflected very slightly in the analyses for August, November and February, but since growth is mainly vertical and grazing pressure on the plants is considerable, the variation in percentage cover is small. Flowering commences in late October, and seed ripens in December. Leaves persist throughout the drought.

(8) Poa laevis is present throughout the year, at a steady cover value between 14-17%. Increased growth in spring is largely counteracted by grazing, while die-back is also significant in many clumps affected presumably by drought or insect attacks at the base (or both). What growth there is, being vertical, is not reflected readily by point analysis. This species is one of the two dominants of this community, both in height and cover value. Flowering is generally poor.

(9) Poa pratensis occurs as for Lolium perenne, though in smaller amounts, and is similarly affected by grazing.

(10) Stipa variabilis is present in small amounts throughout the year in this community; analysis figures seem to indicate a slight increase in the number of plants between April, 1971 and July, 1972. It is much more abundant in more open situations further west where there is less competition from Poa laevis and Carmichaelia. The species is

affected by grazing chiefly in winter, when very many tufts are pulled out of the ground by sheep or cattle, and then left lying on the surface uneaten. In summer when grazing pressure is less intense, the plants flower very freely and set abundant seed.

(11a) Acaena ovina occurs abundantly as the dominant forb. Seedlings germinate early in May, when growth of established plants also commences, and continues vigorously through until November, when dry conditions cause some withering of leaves. This increases into autumn (with some spurts of fresh green growth if rainfall is sufficient). Flowering commences in October, and continues through until January. Young flower heads are much eaten by hares.

(11b) Acaena novae-zelandiae is much less abundant than Acaena ovina, being somewhat localised and not actually present within the bounds of the community studied at E. Its phenology follows a similar pattern to that of Acaena ovina, but it is more resistant to drought. There are many hybrids between these two species.

(12) Calystegia soldanella occurs infrequently. New leaves appear above ground in late September, and vegetative growth reaches a peak in late October or November, but plants in this community remain small. Flowering occurs sparsely in mid-summer; leaves begin to wither in the drought of summer, and all aerial shoots finally die back with the onset of cold temperatures in early June. The plant perennates by buried rhizomes.

(13) Carmichaelia appressa, which is co-dominant with Poa in this community (though less frequent further west) is present throughout the year at a steady fairly high cover value. In spring, 1971, considerable growth occurred, slightly compensating for considerable grazing depletion by sheep and hares, which bite off young shoots, and by cattle, which wrench off large branches or macerate them while still attached. There is a long flowering period from October to January, flowers being produced on old wood, and relatively unaffected by grazing.

(14) Cerastium glomeratum. Large numbers of seedlings germinate in July to August, but, owing to intense competition for water, most fail to survive to the flowering stage in October to November.

(15) Hypochaeris radicata occurs here in only small numbers throughout the year, the generally closed nature of the community being unfavourable. Seedlings germinate in early May, and vegetative growth reaches a peak between September and November. Flowering extends over a long period, from early spring until late summer. The outer leaves begin to wither as summer drought commences, but spurts of new growth occur right through into autumn if there is sufficient rainfall.

(16) Rumex acetosella is common. Seedlings germinate and vegetative growth of established plants commences in late April to May, and growth continues slowly through the winter, reaching a peak in early spring. Flowering occurs from October to November, often continuing after leaves have begun to wither from drought. Sporadic new growth occurs after summer rains, but in severe drought many plants lose all their leaves, surviving only by their underground rhizomes.

(17) Silene gallica follows the same pattern as Cerastium, and occurs in about the same numbers.

(18) Trifolium arvense occurs rarely. Seedlings which germinate in early May make slow growth through the winter and generally fail to survive competition from larger species in the spring.

(19) Trifolium fragiferum also occurs rarely and follows the same pattern as Trifolium arvense.

(20) Triquetrella papillata is easily the predominant moss, covering about 40% of the ground, generally beneath other species such as Carmichaelia, grasses and forbs, but sometimes forming the only ground cover. The seasonal variations shown in the analysis seem to be mainly due to the considerable shrinkage of the plants during dry spells, followed by a marked sudden expansion of area as a result of water absorption after a shower. No reproductive organs were observed at any

period.

It is noticeable that only 1-3% of the surface is normally bare - slightly more in autumn.

Litter is always fairly abundant, consisting of woody fragments of Carmichaelia, dead leaves (often still attached to the plant) of perennial grasses, together with shrivelled leaves of annuals and perennial herbs, the latter more abundant in late summer.

Sandy Flat Community, Station D.

(Note: For species already referred to in E, phenological notes are here omitted.)

(1) Bromus diandrus occurs rarely (less than at E).

(2) Lagurus ovatus is present in slightly higher proportion than at E, and here, in conjunction with Trifolium arvense and Raoulia australis, makes the most significant contribution to ground cover.

(3) Notodanthonia unarede contributes a small but significant percentage.

(4) Stipa variabilis is present in similar amounts to Notodanthonia, being more abundant here than at E.

(5) Acaena ovina occurs rarely (less than at E).

(6) Hypochaeris radicata occurs rarely (less than at E).

(7) Pimelea prostrata is present occasionally. Although considerable growth was noticed between August and November, it was mainly vertical and, therefore, not strongly reflected in the analysis. Flowering extends over a long season, being at its peak in early September. Some seeds were produced.

(8) Raoulia australis is the dominant perennial of the community. Growth commences in August, and continues slowly through spring, summer and early autumn. The apparent decrease indicated by the later analyses is accounted for by the drying-off of some fairly young plants from drought, and the destruction of some by the trampling of animals.

Flowering occurs in November and seeds are shed from December to January.

(9) Scleranthus uniflorus is present in very small numbers. Growth commences in August, and continues very slowly into summer or early autumn. Flowering occurs in November and seeds are shed from December to January. A number of young plants died in the summer drought or were destroyed by trampling (to which the species is more vulnerable than Raoulia because of its single taproot).

(10) Rumex acetosella is present in significant amounts throughout the year, although shoots are generally shrivelled by early summer.

(11) Trifolium arvense is the dominant annual, germinating early in May and continuing to grow slowly throughout the winter. Vegetative growth has usually finished by the end of September, but flowering, which starts early in November, generally continues into January. The total leaf area of each plant is always small, generally only about 6 pairs of leaves; these may be shrivelled and brown by late spring, or remain green until late summer, depending on rainfall. Abundant seed is set from December to March.

(12) Triquetrella papillata occurs in this community only in a favourable wet season as in the autumn of 1972.

It is noticeable that more than a third of the surface is bare, and, as a third is also covered only by litter, (contributed largely by the dead portions of Raoulia plants), the proportion of living plant cover is very small.

Rear dune community, Station C.

(1) Bromus diandrus, though less abundant than at E, makes a significant contribution to the annual plant cover.

(2) Lagurus ovatus is the dominant annual, occurring in similar numbers as at D. Noticeably fewer seedlings appeared in the winter of 1972 compared with 1971, apparently because of colder temperatures.

(3) Desmoschoenus spiralis on this particular dune is subordinate to Muehlenbeckia and Carmichaelia, but this appears to be exceptional. Growth commences in August and continues until autumn; owing to very slow sand increment on this site, growth is not markedly stimulated. Flowering starts in early November and continues into December; abundant seed is shed from December to January, but none was ever found germinating.

(4) Calystegia soldanella is present very occasionally.

(5) Carmichaelia appressa is present in significant amounts but is in a much-chewed, moribund condition (except where protected by Muehlenbeckia, when it produces long erect shoots over a meter high). In spite of this, a few plants flower and set abundant seed. No young seedlings were observed - in fact, most plants appeared to be very old, judging by the thickness of their main stems and roots (see later).

(6) Hypochaeris radicata occurs only in small numbers but contributes significantly to the cover on open sandy patches.

(7) Muehlenbeckia complexa is the dominant species on this dune, although farther west it tends to be replaced by more Desmoschoenus - possibly a reflection of greater fire-damage there in the past. It commences vegetative growth in August, when new leaves appear, followed by the extension of shoots up to a metre during spring and early summer; these are readily shrivelled by salt-laden winds from the south, maintaining the general height of plants at about one metre. There is a very long flowering season extending from early November into January or even February. Abundant seed is produced from December to March, but no seedlings were ever observed.

(8) Rhagodia triandra occurs occasionally, growing only in the shelter of Muehlenbeckia clumps, since it is highly palatable to stock. It makes considerable growth in spring and flowers in October-November; fruit is ripe in December.

(9) Rumex acetosella makes a significant contribution to the cover on open patches.

(10) Triquetrella papillata occurs in small amounts under Muehlenbeckia; just beyond the limit marked for study, on the south slope of this dune, this moss forms continuous ground cover together with Acaena and Rumex.

Over a third of the surface of this site is bare - more in winter, when the Muehlenbeckia is leafless.

Litter is made up partly of woody fragments of Carmichaelia and Muehlenbeckia, and partly of the dead leaves of herbs.

Blowout community, Station B.

(1) Lagurus ovatus is present very rarely.

(2) Zoysia minima makes a significant contribution; it is the only grass that keeps on growing through the hottest and driest periods, but growth is arrested for about three months by the cold temperatures of winter. No flowers were ever observed during 1971-72.

(3) Desmoschoenus spiralis occurs rarely. A few established plants, perched on small mounds of sand, seem to indicate incipient dune-building. There are a few young plants, perhaps two or three years old, but none younger.

(4) Hypochaeris radicata is present very rarely.

(5) Raoulia australis is the physiognomic dominant of the community. Although numbers are relatively small, the mature plants form hummocks in a characteristic pattern which is most striking (see reference later). Many seedlings germinated in June, but very few survived.

(6) Rumex acetosella occurs very rarely.

(7) Scleranthus uniflorus occurs occasionally.

Fore dune community, Station A.

(1) Lagurus ovatus occurs in much the same frequency as on the inland dune.

(2) Desmoschoenus spiralis is easily the dominant species. The analyses indicate a slight increase in density between 1971 and 1972. There appears to be just enough sand accumulating to suit its requirements here, although on the eastern slopes wind erosion has exposed some rhizomes and plants are in the process of decay.

(3) Calystegia soldanella although present only occasionally, is noticeable in summer at the peak of its growth, when stems up to 30cm long twine through the pingao.

(4) Carmichaelia appressa is unusual on the fore dunes, but on this patticular site a group of plants flo rish and flower abundantly.

(5) Hypochaeris radicata makes a significant contribution to the ground cover.

(6) Rumex acetosella is present occasionally.
About half the surface is bare sand.

3. OBSERVATIONS ON MORPHOLOGY AND PHENOLOGY OF THE DUNE SPECIES.

The morphology, physiology and phenology of plants adapted to such a harsh environment as the Spit are of considerable interest.

In the case of most species, the general morphology of the aerial parts has been described adequately elsewhere. The internal leaf anatomy of some of the indigenous species has been described in detail, e.g. Pegg (1916) dealt with Poa laevis, Carex pumila and Desmoschoenus spiralis, and Foweraker (1917) dealt with Raoulia australis and Scleranthus biflorus (similar to Scleranthus uniflorus). In view of this, only a general appraisal of shoot characteristics is made in the present study (sub-section (a) (i) below).

Very little seems to have been written about the subterranean parts of indigenous dune species, only passing references being made in the above papers, and in Cockayne (1928). McIndoe (1932) has written a detailed account of the root systems of Poa laevis, Raoulia australis, and Carmichaelia petrei (likely to be comparable with Carmichaelia appressa). Because of the great significance of root development in plants of dry habitats, some investigations were made (sub-section (a) (ii), below).

Physiological studies were considered beyond the scope of this study, but some reference to this aspect is made in Ch. 5. I. 1. Phenological observations are noted in sub-section (b) below.

(a) MORPHOLOGY.

(i) Aerial Shoots.

The leaves of the indigenous forbs and shrubs typically show the following macroscopic features:

Small leaf size, with compact vein networks; leaf texture hard and leathery, with strong cuticle development, e.g. Scleranthus uniflorus, Cyathodes fraseri, Muehlenbeckia complexa, Coprosma propinqua, Hymenanthera alpina. Some exceptions which have larger leaves are Rhagodia triandra, (which is fleshy and likely to have physiological drought resistance, Myoporum laetum, which produces a gummy secretion protecting its young leaves, and Craspedia lanata, which has both leaf surfaces protected by a dense tomentum, a feature also shared by the small-leaved Raoulia australis). In some shrubs leaves are present only during spring, e.g. Discaria toumatou, while in others leaves are almost or entirely absent, e.g. Carmichaelia appressa and Carmichaelia corrugata, Muehlenbeckia ephedrioides, Clematis afoliata and Rubus squarrosus. Typical microscopic features of leaves (from the studies mentioned at the beginning of this section) include high stomatal frequency, small mesophyll-cell size, thick cell walls, palisade tissue several layers thick, and a large proportion of collenchyma tissue. The leaves of the adventive forbs by contrast are generally lacking in the features described above, e.g. Rumex acetosella, Hypochaeris radicata, Trifolium arvense. The indigenous graminoids, e.g. Desmoschoenus, Carex species, Zoysia, Notodanthonia, Poa laevis, and also the adventive grasses Stipa variabilis and Ammophila arenaria have rigid, narrow, rolled or folded leaves, but most of the adventive grasses, such as Lagurus and Bromus diandrus have relatively broad, flat, soft leaves.

Stem structure of both indigenes and adventives is generally characterised by short internodes. This results in compact shrubby forms, as seen in Muehlenbeckia complexa, Hymenanthera alpina, and Discaria toumatou, or, in the case of forbs, rosette forms as in Hypochaeris or mat or cushion forms as in Raoulia and Scleranthus.

Fig. 63. Raoulia australis on blowout, showing seaward side dead, new growth proceeding from sheltered north side.

Fig. 64. Raoulia australis : a more extreme example than the above, showing the last stage of the plant succumbing to sand-burial and abrasion.

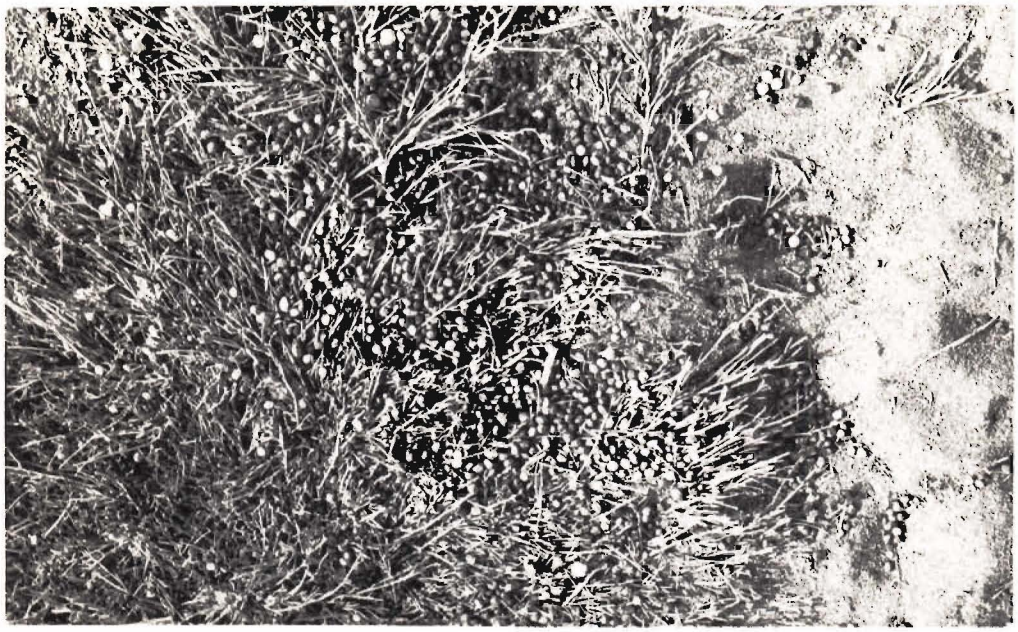


Fig. 65. Carmichaelia appressa, surface view of extreme prostrate form, closely cropped by hares, rabbits and sheep; old dune area.

Fig. 66. Carmichaelia appressa, upright form, (1a); on north side of rear dunes, protected by Bayley's stock fence.

Some unusual growth forms warrant special mention. The specimens of Myoporum laetum, Dodonea viscosa and Sophora microphylla growing on the dunes are all limited to about 2m in height; their tops present a horizontally "shorn" appearance; while their branches on the windward side (SW) are leafless, and growth has proceeded solely from the lee side (Figs. 57, 59, 61). Shrubs of Muehlenbeckia complexa and Clematis afoliata develop such features in less extreme form; in their case it is very noticeable that soft new shoots, produced in spring, up to 40cm above the main level of the bush, are cut back by the first strong SW storm. Raoulia australis plants growing in the blowout areas develop into hummocks, up to 15cm high and elongated parallel with the SW wind, by the following process:

Young plants of the typical mat form provide enough wind resistance to cause sand deposition, through which shoots continue to elongate vertically, but the bases of these stems die off, necessitating development of new adventitious roots from further up the stem; after a few years, the plant becomes perched on a mound of sand up to 15cm high, which remains completely dry at all times, owing to the water-repellant nature of the closely-packed "woolly" leaves. At this stage, water stress apparently becomes too severe to allow further root development, and further vertical shoot growth thus becomes impossible. As the mound has been growing, shoots on the exposed SW side have died off progressively, while the plant continues to spread by vegetative reproduction on the sheltered NE side (Figs. 63, 64).

The causes of the above forms are discussed in Ch. 5, I. 1.

(ii) Roots and Rhizomes.

The underground parts of a number of indigenous species were excavated. In the case of those with roots no more than 60cm deep an attempt was made to trace out the entire system (recognizing that the finest terminations must inevitably have been broken in the process). For deeper

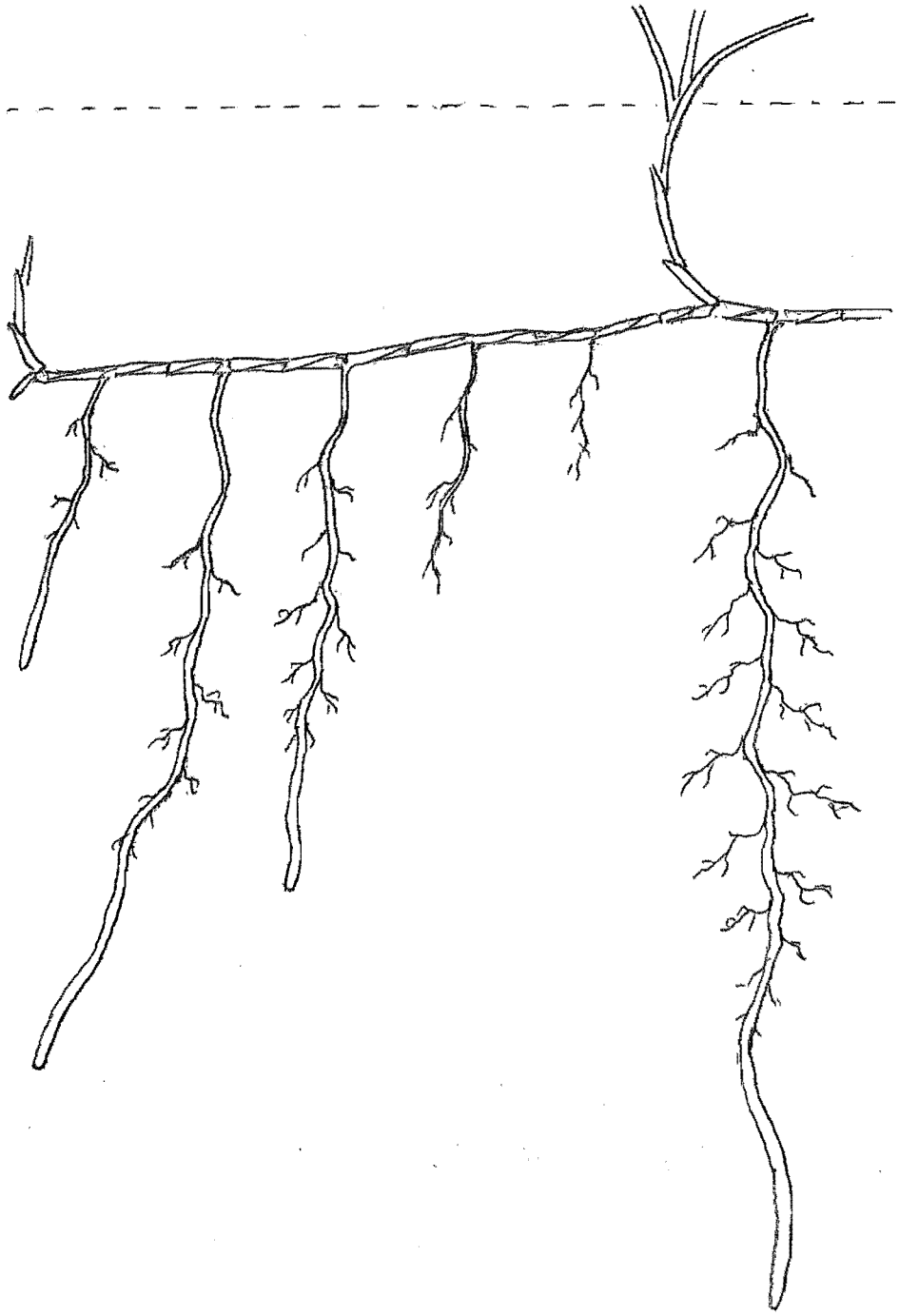


Fig. 67. Carex pumila. Scale 1:3.

The wiry, light-coloured rhizome, 3 mm in diameter, creeps horizontally 10-15 cm below the sand surface; from the nodes which are 2 cm apart are produced scale leaves, with aerial shoots at intervals of 10-20 cm; roots are produced in succession behind the tip of the rhizome; first order roots, 2-3 mm in diameter, may be up to 40 cm long, extending diagonally and generally less than 30 cm below the surface; older part of the root is sheathed in spongy dead tissue, the terminal portion soft and white; second order rootlets up to 2.5 cm long, and fragile third order rootlets, are produced abundantly.

Fig. 68. Desmoschoenus spiralis: roots shown approximately natural size. Rhizome,1 cm diameter,sheathed in dead leaf bases,is found 5-30 cm below surface,dying off progressively as burial proceeds; roots are produced in succession behind the developing aerial shoot;roots up to 50 cm long,upper portion wiry,2 mm diameter, last 3-4 cm thicker,soft and white; abundant fine laterals,2-6 cm long,with persistent root hairs to which sand particles appear to be glued,forming a thick envelope.

Fig. 69. Poa laevis.

A soil profile in the old dune area shows some of the root system of a Poa ,although the complete lateral and vertical extension of the roots is not apparent.The main roots reach a depth of50-70 cm and cover a radius of about 20 cm;colour is pale brown and the diameter of 1 mm is fairly uniform throughout;abundant second and third order roots,the former 5-10 cm long,are produced.

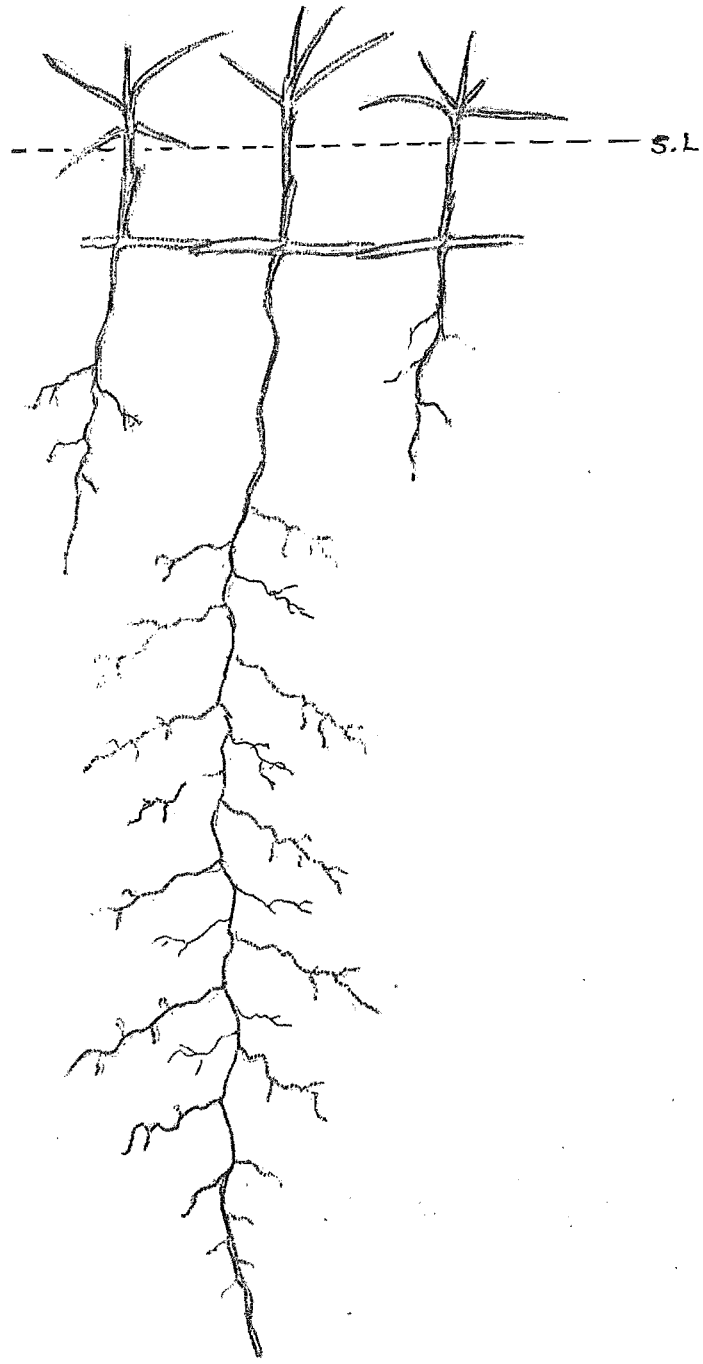


Fig.70. Zoysia matrella. Natural size.

The light-coloured, wiry rhizome, 1 5 - 2 mm in diameter, partly enshcathed by scale leaves, creeps horizontally about 2 cm below the sand surface; from each node (2 cm apart) are produced one or two wiry, light-coloured roots, slightly less than 1 mm in diameter, except for the last 5 mm which is slightly thicker, soft and white; these main roots descend vertically for about 14 cm, producing numerous second order roots up to 1½ mm long; third order roots are very short.

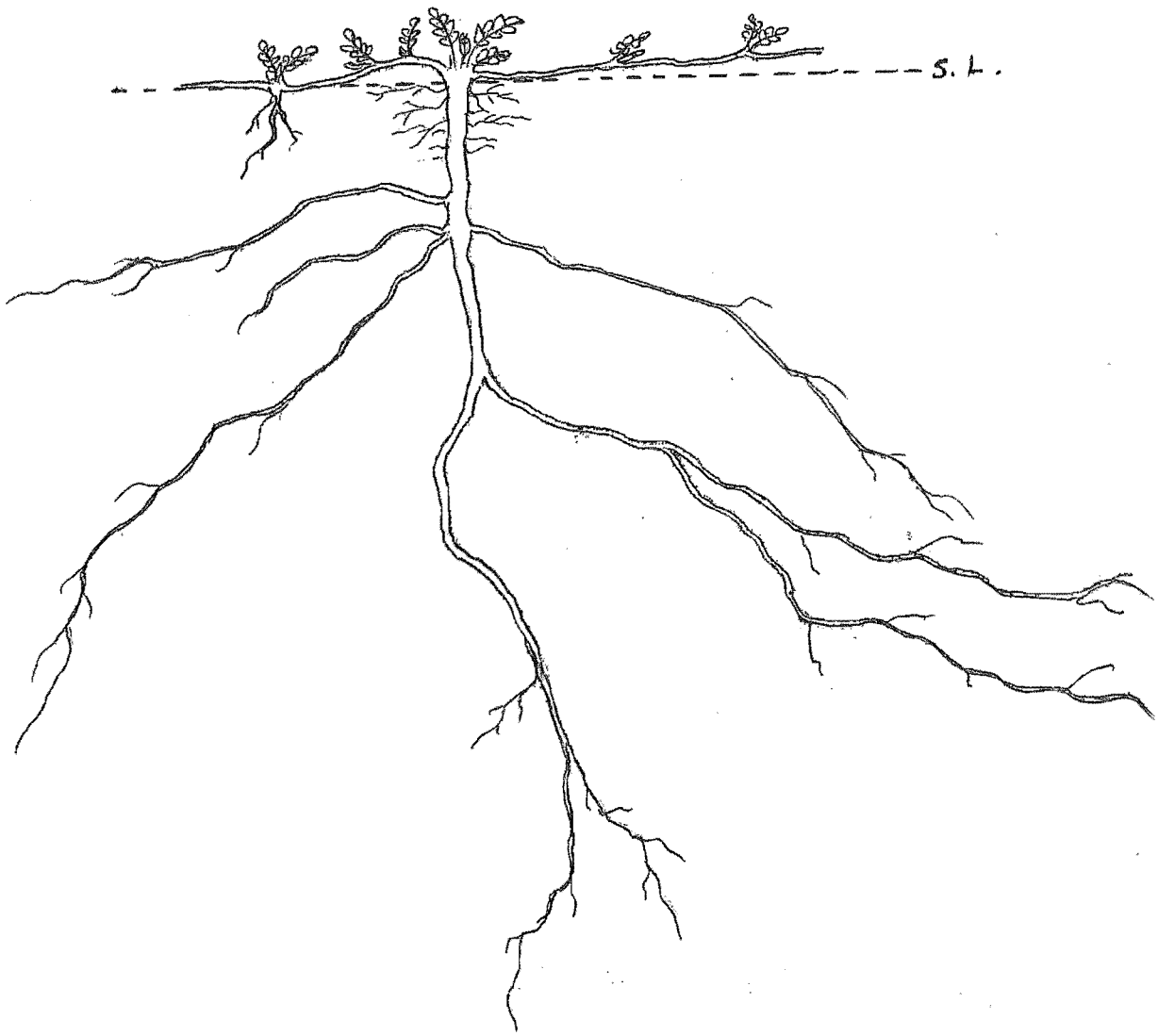


Fig. 71. Acaena novae-zelandiae. Scale 1:4.

A fairly young plant with aerial shoots spreading over a radius of about 13 cm.

The taproot is brown and flexible, about 1 cm in diameter at the top, tapering gradually to a depth of 30 cm; some fine absorbing rootlets, 3-4 cm. long, produced just below the soil surface; at 8-10 cm depth several strong laterals branch out horizontally to a length of 25-40 cm; third order rootlets up to 5 cm. long are produced sparingly. Horizontal surface shoots may produce roots from the nodes.

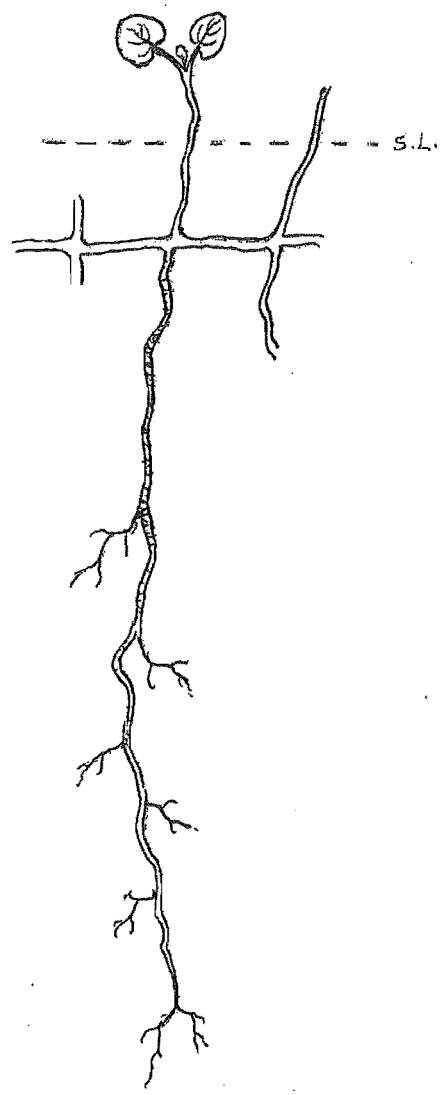


Fig.72. Calystegia soldanella. Scale 1 :4.

A light-coloured, fleshy, brittle rhizome, about 4 mm in diameter, creeps horizontally below the surface at 7- 10 cm depth; older portions get progressively darker and thicker, with a corky covering; each node (about 5 cm apart) produces one or two vertical shoots, terminating in leaves at the surface, and a single brown, corrugated, flexible main root, 3 mm in diameter for most of its length, extending vertically for about 30 - 40 cm; second and third order rootlets are short and sparse.

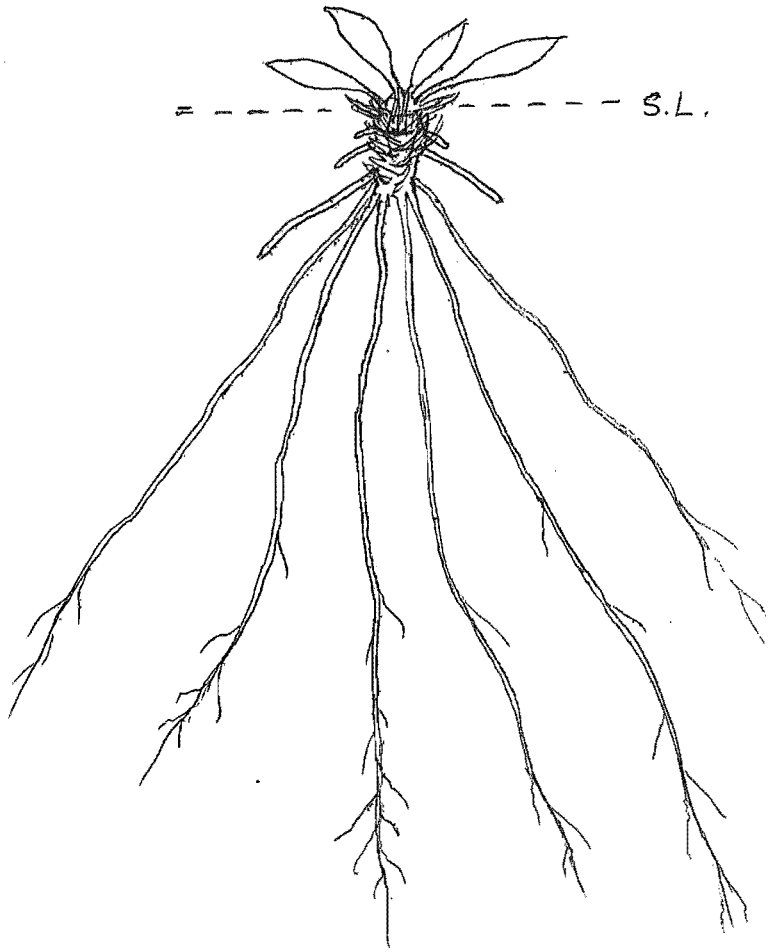


Fig. 73. Crasoedia lanata. Scale 1:3

A mature plant. Roots are produced from a short, thick rhizome 3–4 cm long, which is sheathed in decaying remains of leaves; roots are fleshy, brittle, light fawn in colour, about 3 mm in diameter for most of their length; they extend diagonally and vertically for 20–35 cm; second and third order roots are very sparse and almost entirely confined to the lower extremities.

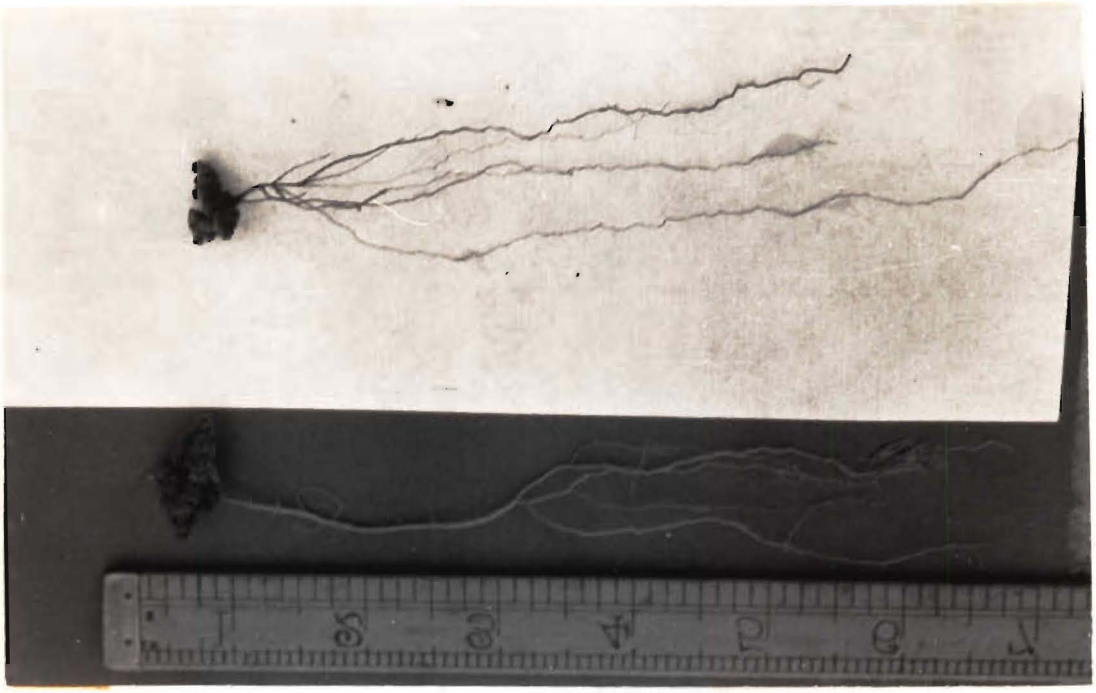


Fig. 74. Upper: Raoulia australis.
A young plant, about two years old, showing several very slender roots arising from the base of the stem.
Lower: Scleranthus uniflorus.
A young plant, about two years old, showing strong taproot which branches out lower down. Scale 2/3 natural size.

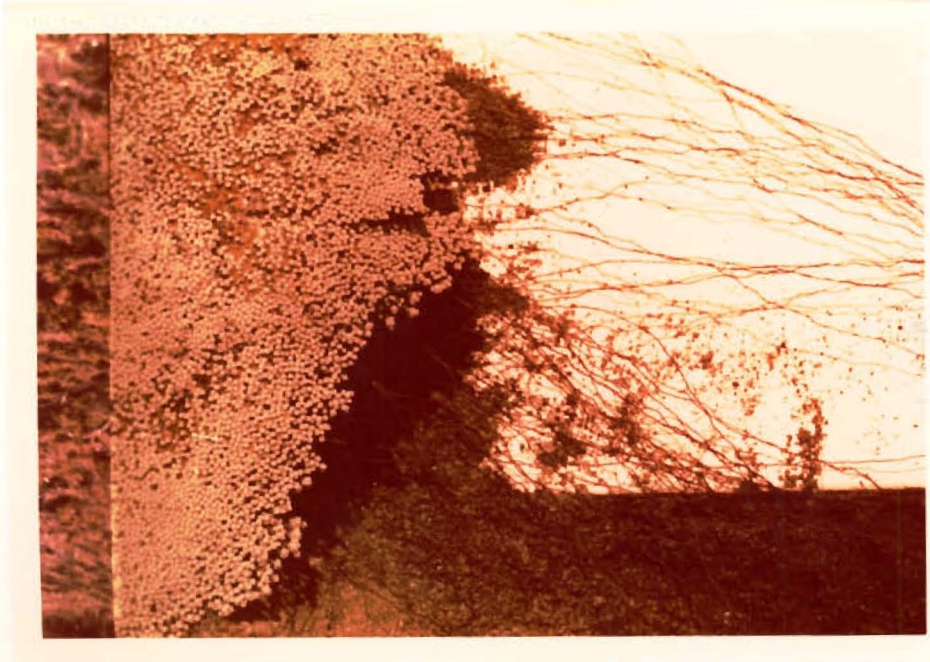


Fig. 75. Raoulia australis.
Nearly horizontal roots exposed 3-5 cm below the surface.

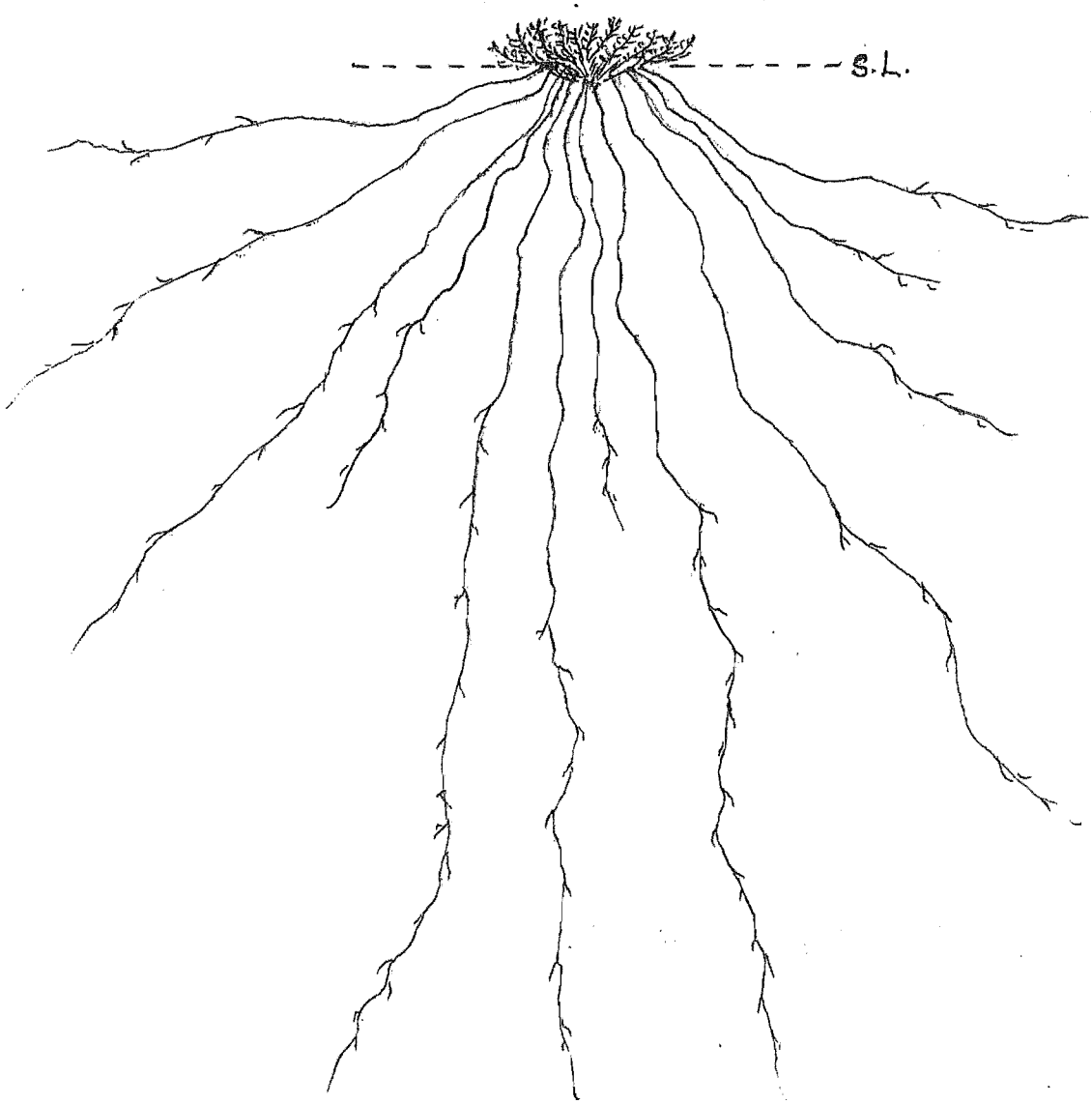


Fig. 76. Raoulia australis. Scale 1:4.

A young plant, 8 cm in diameter and 2.5 cm high. Numerous very fine, wiry, dark brown roots produced from stem bases; root diameter of 0.5 mm or less; unvarying throughout their length, which is from 45–70 cm; some roots extend almost horizontally, others diagonally and vertically; second and third order rootlets less than 1 cm long, very fragile; and sparse.

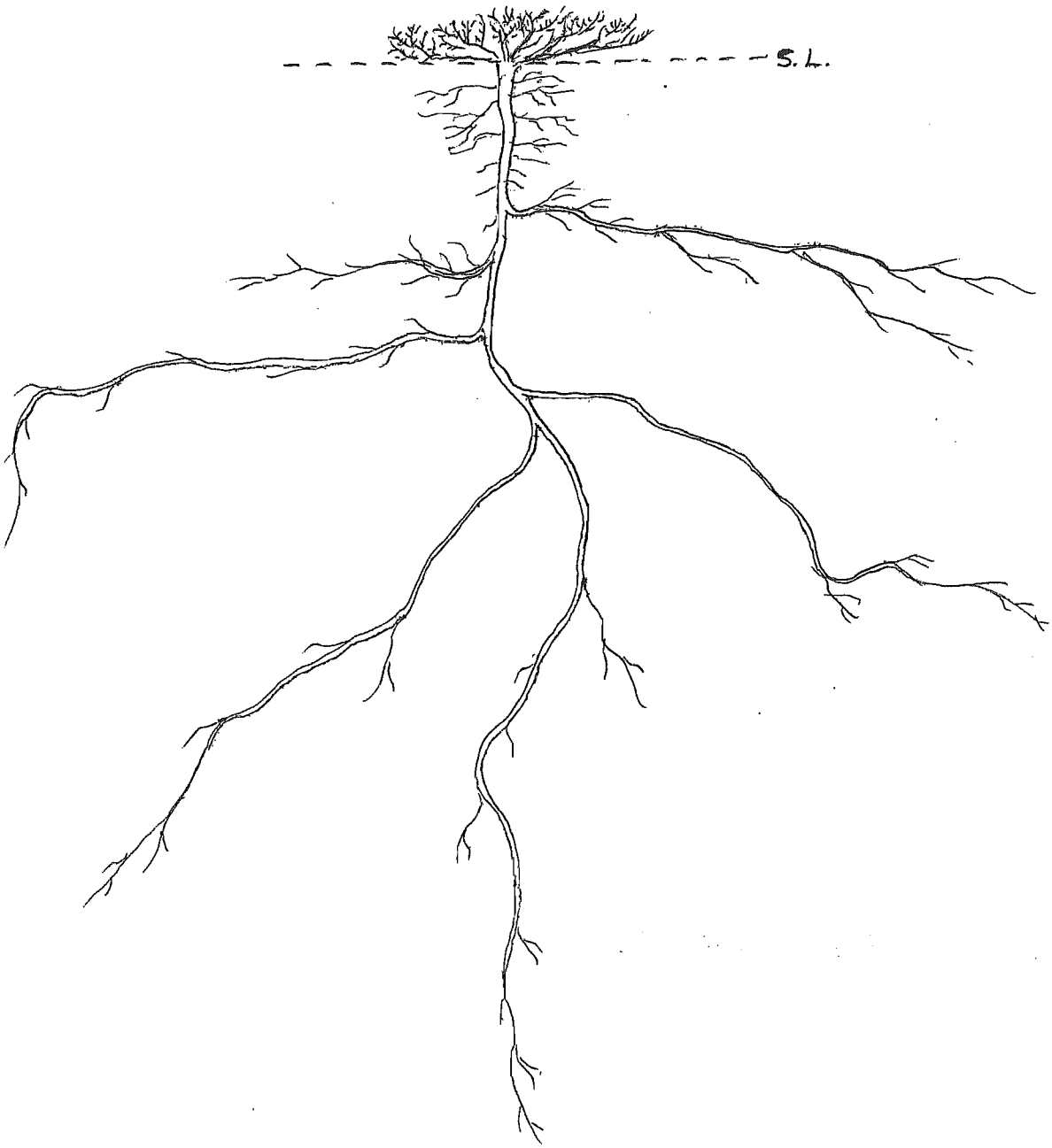


Fig. 77. Scleranthus uniflorus. Scale 1;4.
A mature plant, 15 cm in diameter and 4 cm high. The taproot is yellowish brown, tough and flexible, 6 mm in diameter at the top, tapering gradually to a depth of 60 cm; several strong laterals produced 10-15 cm below the surface extend diagonally for 20-40 cm; second and third order roots up to 10 cm long are produced sparingly; some fine absorbing roots 5-10 cm long come off the main root just below the soil surface.

Fig. 76 . Carnicuselia appressa.

Old plants with root system extending to c. 40 cm across and 30 cm high. Bark brown, rooty to roots, 3–6 cm diameter at top, tapering gradually to a depth of 2 to 4; strongly developed laterals come off horizontally at 30–50 cm depth, some fine absorbing rootlets occur just below the soil surface (Fig. 82); second and third order roots occur sparingly, mainly below 1m depth (Fig. 83); root nodules, brown, ovoid, 5 mm long, present in small numbers.

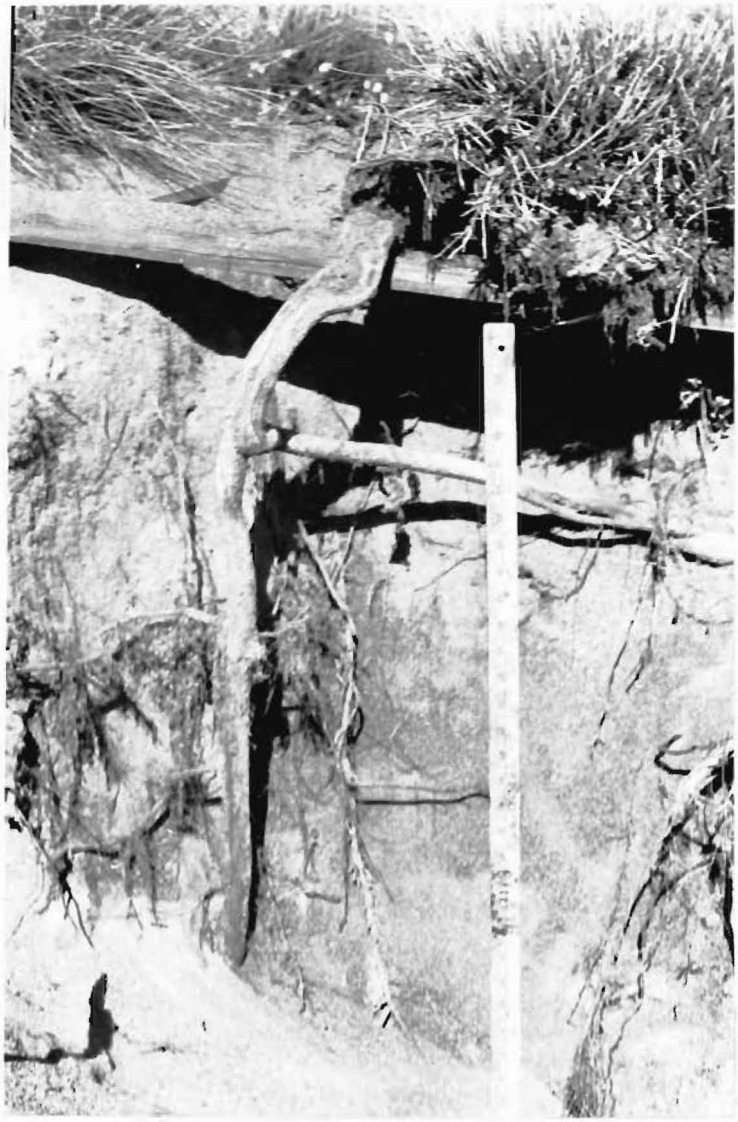


Fig. 79. Carmichaelia appressa.

See description for Fig. 78.

Fig. 80. Caraichaelia appressa.

This plant, growing on the rear dunes, had roots 3 m long, (most of the terminal portions not shown).

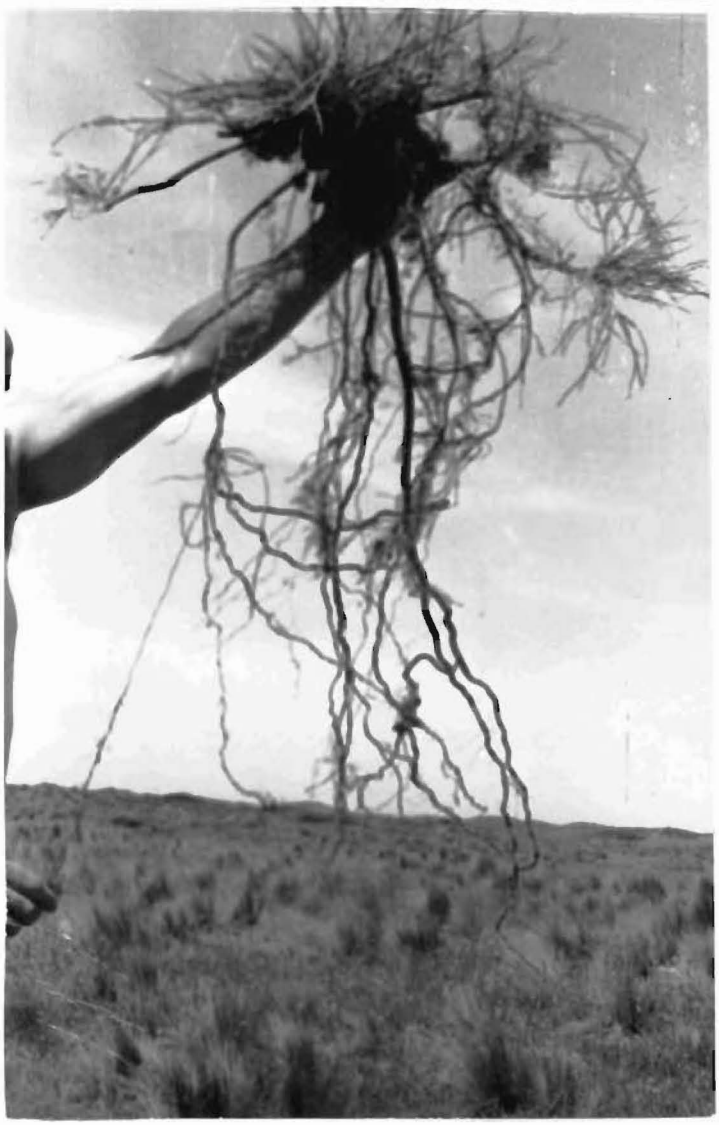


Fig. 81.

Caraichaelia growing on old dune area, had taproot and several strong laterals at least 3 m long.

Fig.82.Carmichaelia. Fine laterals up to about 8 cm long produced from the top of the main root.

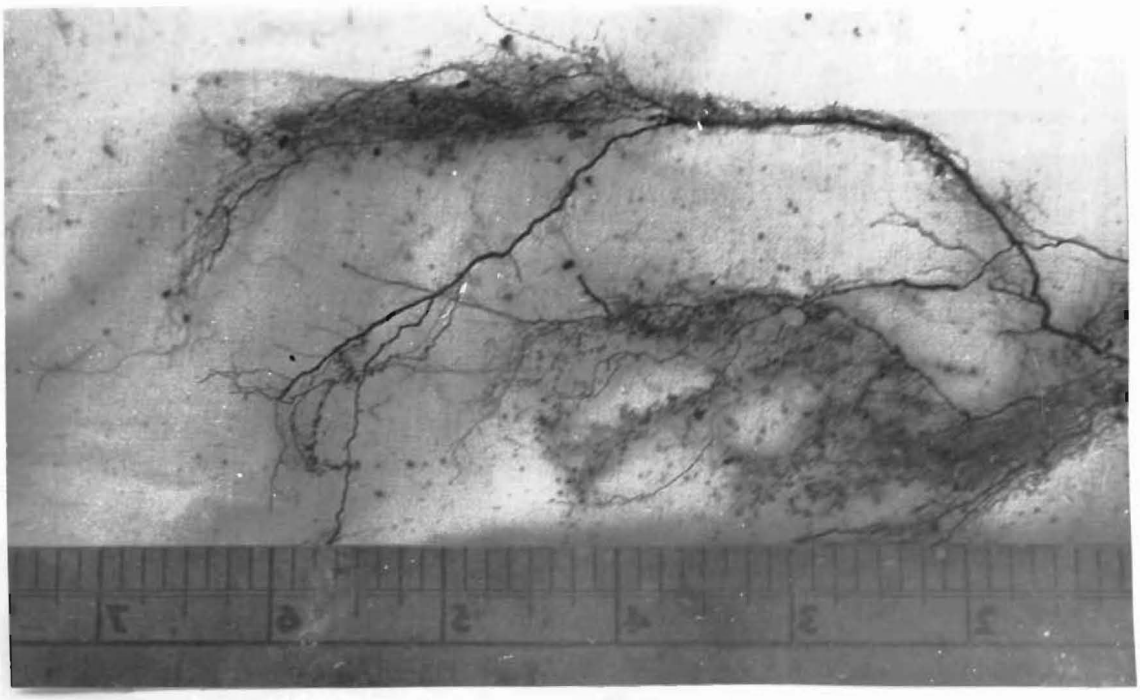


Fig.83.Carmichaelia.

Terminal portions of roots showing second and third order rootlets, with a few root nodules.

Fig. 84. Dodonea viscosa.

An old plant, most of its original branches and roots dead, but with new shoots and adventitious roots developed from buried horizontal branches. A woody taproot, 6–8 cm in diameter at the top, with three strongly developed laterals 3–5 cm in diameter, produced 20 cm below ground level and extending near-horizontally for 4–6 m, fine rootlets produced sparingly, mainly in the distal portions.

Fig. 85. Dodonea viscosa.

As above.

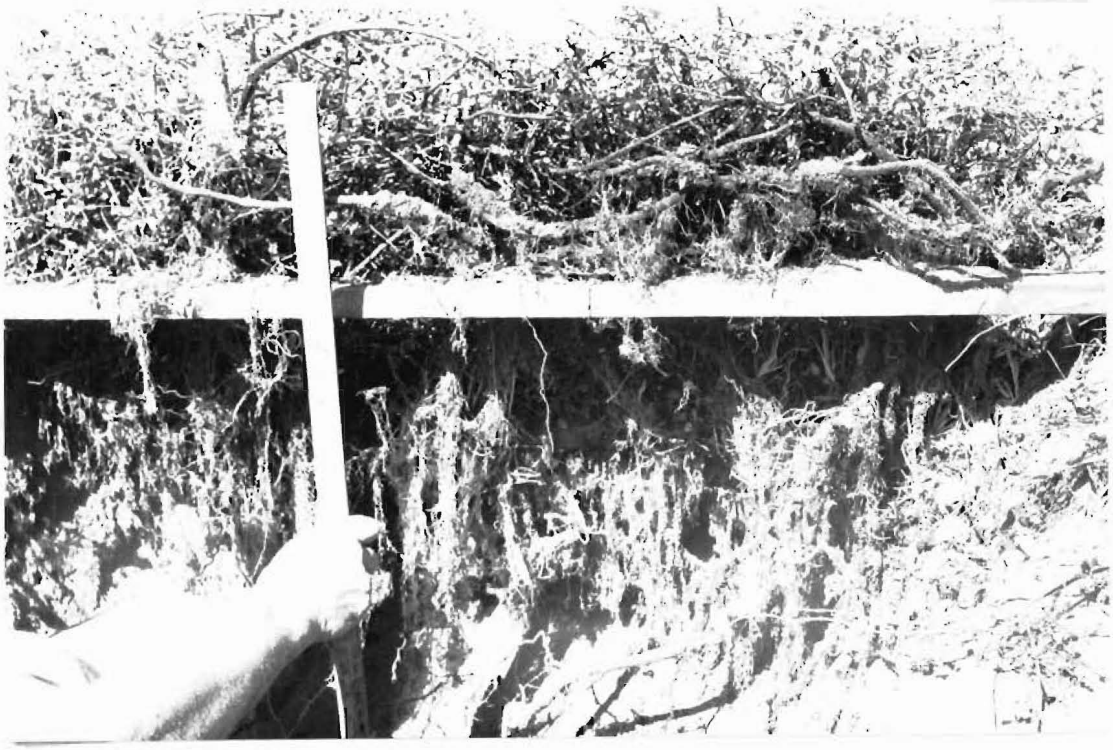


Fig.86. Muehlenbeckia complexa .

An oldplant growing on the rear dunes.

Roots dark brown, tough and flexible, 0·5-1 cm diameter at the top, tapering gradually, to a depth of 1·5-2 m; many individual roots of equal size, much twisted, forming a tangled mass; second and third order roots produced sparingly; some fine absorbing rootlets are developed on the lower side of buried stems, and suckers may arise from horizontal roots.

The above features are more clearly visible in Fig.87 than in Fig.86; in which Muehlenbeckia roots are obscured by fibrous roots of the annual grass Bromus diandrus.

Fig. 67. Muehlenbeckia complexa.

For description, see Fig. 66.

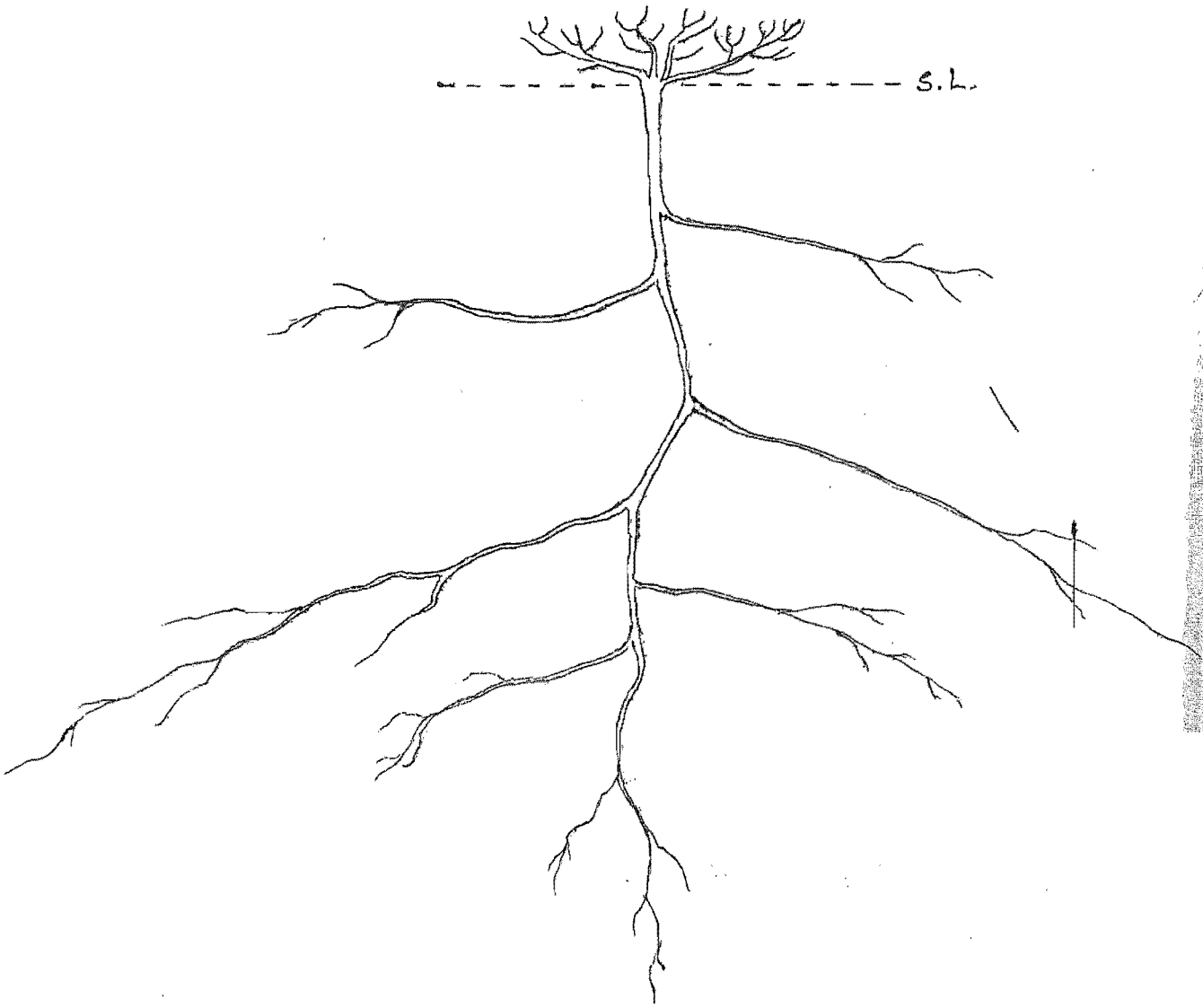


Fig. 88. Pimelea prostrata. Scale 1 : 5

A fairly young plant, with aerial shoots spreading over a radius of 9 cm, height 6 cm.

AAtaproot, light in colour, tough and flexible, measures 5 cm in diameter at the top and tapers gradually to a depth of 60 cm; several strong laterals extend near-horizontally, 6-10 cm below the surface, for a distance of 25-40 cm; second and third order roots are produced sparingly, mainly on the distal portions.

roots only partial excavation was possible, although in the case of Carmichaelia and Muehlenbeckia a depth of 2m or more was reached. Because it was undesirable to sacrifice indigenous plants unnecessarily, the number of specimens investigated was only three or four of each species. In the case of Dodonea only one plant (thought at first to be dead) was partially excavated, the sand then being replaced over the roots.

The results are recorded by means of photographs and scale drawings made from field sketches, with descriptive notes, for the following species:

Graminoids:
- Carex pumila (Fig. 67)
- Desmoschoenus spiralis (Fig. 68)
- Poa laevis (Fig. 69)
- Zoysia minima (Fig. 70)

Forbs:
- Acaena novae-zelandiae (Fig. 71)
- Calystegia soldanella (Fig. 72)
- Craspedia lanata (Fig. 73)
- Raoulia australis (Figs. 74, 75, 76)
- Scleranthus uniflorus (Fig. 77)

Shrubs:
- Carmichaelia appressa (Figs. 78, 79, 80, 81, 82, 83)
- Dodonea viscosa (Figs. 84, 85)
- Muehlenbeckia complexa (Fig. 86, 87)
- Pimelea prostrata (Fig. 88)

Some observations were also made on the underground parts of the common adventive species. These are generally well known, and do not warrant individual description, since their root systems are not strongly developed or particularly specialised, with the exception of the following three species.

Acaena ovina. This plant has a stout woody taproot, about 5cm diameter at the top, tapering slightly to a depth of about 25cm, when it commonly divides into several laterals which extend horizontally or diagonally for another 20cm; the upper part of the tap root is generally lacking in any second order roots; third order roots are produced sparingly near the extremities. Offshoots are produced abundantly from

the lower stem of the original plant; these extend horizontally, just below the soil surface, for about 5-10cm before producing aerial shoots and root systems.

Hypochaeris radicata. The roots of this species when growing on the dunes show certain variations from their development when growing in garden loam. The stout fleshy taproot may reach a depth of 36cm, but generally in specimens more than a year old the tap root shows signs of decay, or may be completely shrivelled; its place is taken by a number of stout laterals from near the base of the stem; these extend out over a radius of 20-30cm, some nearly horizontal, close beneath the soil surface, and others diagonally downwards; second and third order rootlets are produced fairly abundantly, especially on the lower portions.

Rumex acetosella. A mature plant may develop a strong, slender, flexible taproot, extending vertically for as much as 60cm, with second and third order roots produced sparingly. At a depth of 8-12cm a number of laterals extend out horizontally, giving rise at intervals to shoots which emerge above ground; in this way one plant rapidly covers a large area.

On the basis of the characteristics of their underground systems, the dune species can be grouped as follows:

(1) Shrubs and trees with thick woody taproots which penetrate from one to several metres deep; these produce proximally a number of stout laterals which extend out near-horizontally often for a considerable distance, only 20-30cm below the surface; fine absorbing rootlets are produced sparsely, notably on the upper parts of the taproot and on the lower portions of the main laterals, e.g. Carmichaelia appressa, Dodonea viscosa, Muehlenbeckia complexa, Pimelea prostrata (on a smaller scale). Species not investigated but probably to be included here are Hymenanthera alpina, Discaria toumatou, and Myoporum laetum.

(2) Perennial forbs with long fleshy or stringy taproots extending to a depth of 30-60cm with fine absorbing roots mainly at their distal ends, e.g. Scleranthus uniflorus,

Fig. 89. Raoulia seedlings,one year old,on blowout.

Fig. 90. Scleranthus seedlings,one or two weeks old,growing on the leeside of a mature plant,on blowout.

Craspedia lanata, Hypochaeris radicata, Acaena novae-zelandiae, A.ovina.

(3) Perennials (forbs and graminoids) with extensive underground rhizomes from which new absorbing roots 15-30cm long are constantly being produced, e.g. Calystegia soldanella, Carex pumila, Desmoschoenus spiralis, Zoysia minima, Rumex acetosella provides a variation having a deep taproot (down to 60cm) and an extensive system of shallow laterals from which new aerial shoots can be produced.

(4) Grasses with strongly developed fibrous root systems penetrating to a depth of 60cm or more, e.g. Poa laevis.

(5) Grasses with relatively weak fibrous root systems - generally 25cm deep or less, e.g. Notodanthonia unarede, Stipa variabilis, Anthoxanthum odoratum, Bromus diandrus, Lagurus ovatus, Aira caryophyllea.

(6) Annual forbs with sparsely branches taproots weakly developed, 10-20cm long, e.g. Trifolium arvense, Silene gallica, Cerastium glomeratum.

(7) Raoulia australis has a unique root system.

Fig. 91. Scleranthus seedlings, four months old, on blowout.

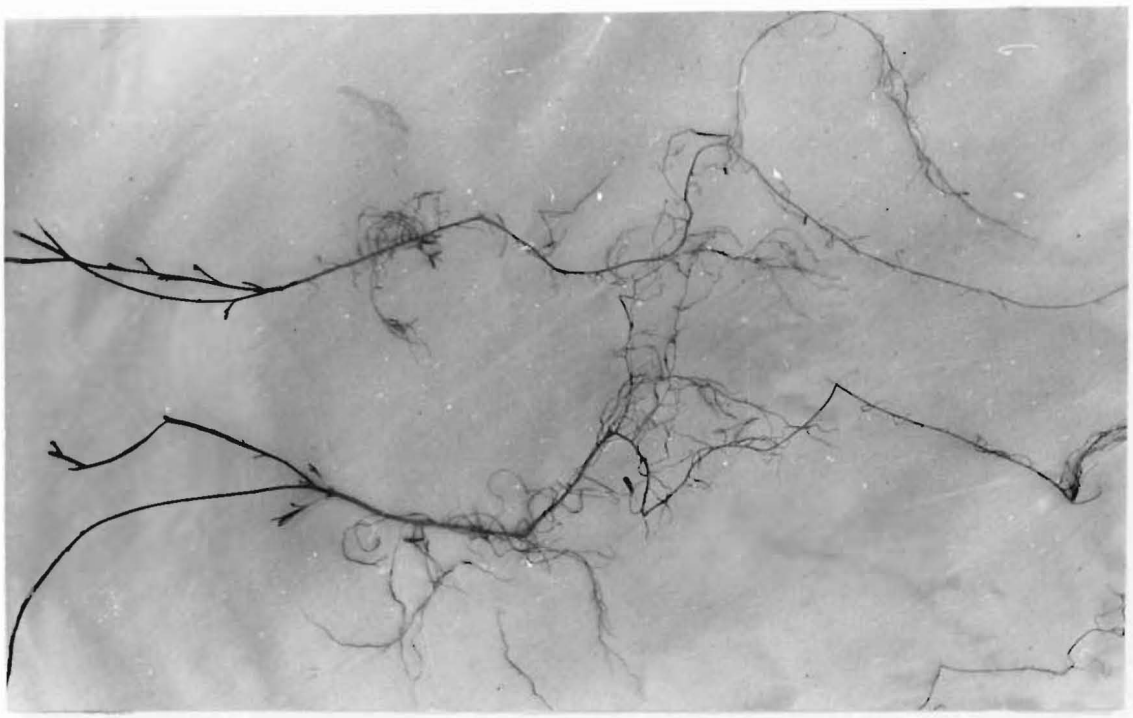


Fig.32.*Carmichaelia* seedlings,five months old.Scale 1:3 approx.
Note a few large root nodules.

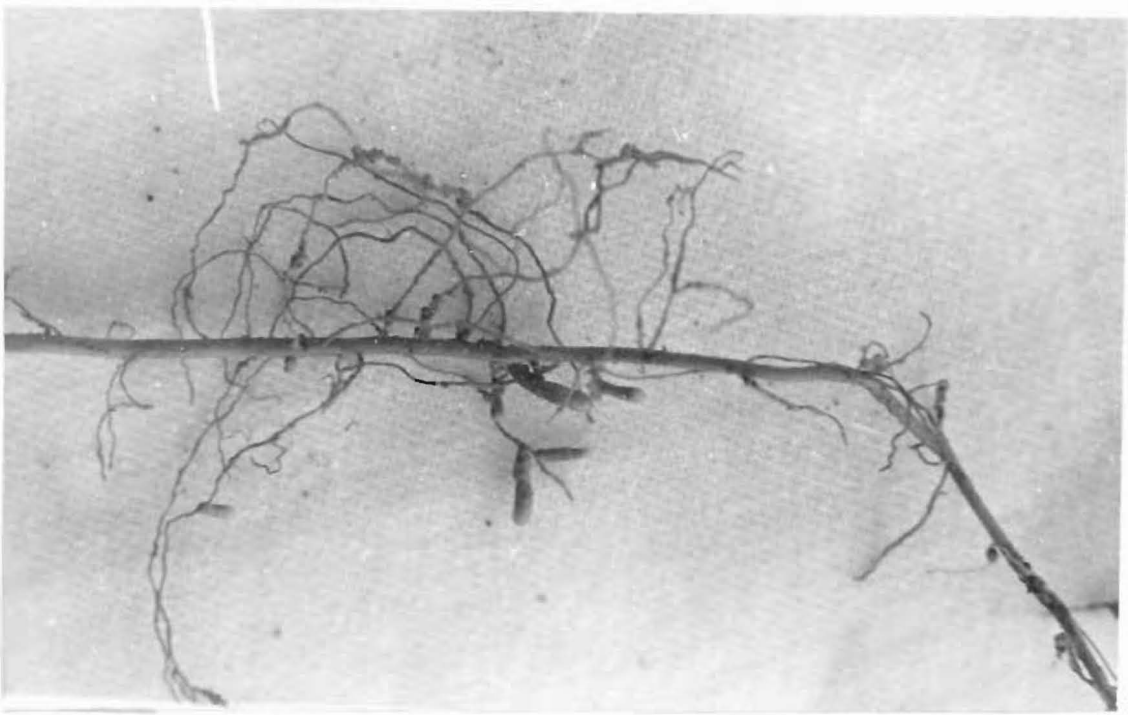


Fig. 33. Detail of root of one of the above plants,approximately
natural size.

Scleranthus seedlings at the cotyledon stage were found at station B on 4 July, 1971. These had developed 4-6 pairs of leaves by 30 August (Fig. 90), and by 30 October each of the surviving plants had produced 4-12 shoots and measured from 6-12mm across (Fig. 91). As with Raoulia, the mortality rate was high, less than 5% surviving the first year. More seedlings germinated in the same area in May 1972, but none appeared to survive the winter.

Note on Carmichaelia seedlings grown in Christchurch.

In the absence of any observations in the field, the following notes on Carmichaelia seedlings observed at the writer's home are included, although no planned investigation was involved.

On 10 April, 1971, 100 untreated seeds of Carmichaelia appressa, collected two months previously, were sown in a box of dune sand, placed in a shade house, and kept well watered. Six weeks later, five seeds germinated, and the seedlings grew slowly throughout the winter. By September each plant was about 5-6cm high and had 4 or 5 leaves. The box was then moved out into the garden in partial shade, and supplied with just enough water to prevent complete drying out. Growth continued fairly rapidly throughout the summer, but unfortunately no systematic records were kept.

On 28 August, 1972, the plants were carefully removed from the box and measured. Length of shoots varied from 9-15cm. Length of roots varied from 39-45cm. The long tap root tapered gradually from a diameter of 3mm at the top, and bore numerous short fine laterals, on some of which were whitish, ovoid nodules, up to 5mm long, about 6 per plant (Figs. 92, 93).

These plants were then replanted in an open sunny situation in the garden, where they continued to thrive throughout the following year, producing numerous shoots, some horizontal and some vertical. On 20 December, 1973, two of these plants measured 30cm high and were producing flowers.

In the autumn of 1972, seeds of both Carmichaelia appressa and C.corrugata, inside plastic bags which were incompletely closed, were inadvertently left lying in a sheltered corner of the garden. In August it was discovered that all of these seeds had started to germinate. The tiny seedlings (about 20 of each species) were transferred to a shady position in the garden. By January 1973 the only survivors were two plants of C.appressa (measuring 2cm high and bearing two or three leaves), and one C.corrugata, somewhat smaller. These too died during the autumn, possibly from fungus attack encouraged by humid conditions.

(ii) OBSERVATIONS ON GROWTH RATES OF SOME INDIGENOUS SPECIES.

The species Zoysia minima, Desmoschoenus spiralis and Raoulia australis were selected for growth measurement because they are important sand-fixing plants which seem able to grow even in the most adverse conditions. Scleranthus uniflorus was also examined, as an interesting comparison with Raoulia, since it occupies the same sort of habitat and has a similar growth form. Carmichaelia appressa, a species which plays an important part on the older-established dunes in particular, was investigated initially, but was abandoned after a few months; because of the plant's peculiar habit of growth it appeared that it was not going to be possible to obtain a systematic set of measurements in the time available. (Several small plants marked for observation of increase in overall height and diameter made no observable growth in a year, while on three larger plants the shoots which did elongate were invariably other than those which had been previously marked and measured). Since only a few plants of each species were measured, the results cannot be taken as representing a reliable population sample.

In May 1971 plants for observation were marked with numbered stakes as follows:

(i) Zoysia - plants (a), (b), (c), (d), (e), scattered at various points on the blowout at station B.

(ii) Desmoschoenus - plant (a) on the steep south-east slope of the fore dune at station A; plant (b) on the western slope

dune; plant (c) on the north-east slope of the same dune; plants (d) and (e) were isolated seedlings, perhaps two or three years old, each having only five or six small leaves about 10cm in height, situated in the middle of the blowout at station B.

(iii) Raoulia - plant (a), measuring 23 x 18cm, was at the foot of the northern slope of the rear dune at C; plants (b), (c) and (d), measuring 2-3cm, and plant (e) 18cm in diameter, were on various parts of the blowout B.

(iv) Scleranthus - plant (a) measuring 7cm in diameter was on the sandy flat at station D; plants (b) and (c) about 2cm in diameter; plant (d) 30 x 12cm; and plant (e) 9 x 12cm were on various parts of the blowout, station B.

All of the above specimens except for the three large Desmoschoenus plants on the dunes, were protected from the depredation of browsing animals by a covering of wire netting pegged down with heavy fencing wire; it was considered that any more elaborate covering would upset normal patterns of wind movement and sand deposition.

Subsequent observations of these plants suffered certain setbacks:

Zoysia - one plant was interfered with by an intruder removing the stake, and another ceased growth of the marked rhizome after the tip was exposed by wind erosion.

Desmoschoenus - plant (c) for reasons unknown stopped growing altogether after September 1971.

Raoulia - one of the small plants was destroyed by the hoof of a cow, and plant (e) proved to be moribund, making no observable growth.

Scleranthus - the two smallest plants succumbed to drought during the summer of 1971, and the largest plant possibly having reached normal maximum size, made no further growth.

All plants were measured on the following dates: 10 September, 18 December, 1971, 10 February, 12 March, 6 May, 2 June, 1 August, 28 August, 1972.

One plant of each species was finally checked again in January 1973.

Details of methods used in measuring:

Zoysia - a single isolated rhizome was selected, and the distance of its growing point from the stake was checked on each occasion. The rhizomes are generally 5-8cm beneath the surface; nodes bearing groups of two or three leaves occur at regular intervals, spaced about 2-5cm apart; the terminal three nodes bear no roots; roots develop at the fourth node, and leaves appear above the surface at the fifth node. Because of the loose sandy nature of the substrate, it was easy to excavate the end of the rhizome, (its position being marked at the surface by a stone) and replace the sand after measuring without disturbance to roots or shoot tip.

Desmoschoenus. Plants (a), (b), (c) had long shoots trailing down the slope; because the growing point of the stem is completely hidden by the closely-packed leaves, measurements here were mostly of leaf extension, plus a small increase in stem length. A stake was fixed where the young terminal leaves (about 5cm long) were just touching it. On subsequent visits, the distance that the shoot had grown past the stake was measured. A similar procedure was followed for the seedling plants; here the stem apex was below the sand surface, and measurements were made of the length of young leaves, from first appearance until they reached a height of about 10cm, (at which stage their tips started to wither and growth ceased).

Raoulia. This being a mat or cushion form, with leaves too small to count or measure readily, was measured by increase in diameter of the whole plant. Plants normally grow fairly flat and with a circular outline, unless an obstacle is met, or some special circumstance such as sand-accumulation occurs. Two fixed diameters were marked on the wire netting above each plant; growth measurements represent the average of these (i.e. amount of increase).

Scleranthus was similarly measured by increase in diameter of whole plants, which grow as small cushions of circular outline.

Table 8. Annual growth increments, measured for three indigenous species, Oct.1971-Sep.1972.

(i) Zoysia minima

		plant a			plant b			plant c		
1971	Weeks	cm	yr%	wk%	cm	yr%	wk%	cm	yr%	wk%
Oct. 10–Dec. 18	14	24.0	30.0	2.2	15.0	30.0	2.1	12.5	37.0	2.6
1972 Feb. 10	7.5.	18.0	22.0	3.0	12.5	24.0	3.2	7.5	22.0	3.0
Mar. 12	4.5	17.5	22.0	5.0	12.0	23.0	5.0	7.0	21.0	4.7
May 6	8.0	15.0	19.0	2.4	9.0	17.0	2.1	5.5	16.0	2.0
Jun. 2	4.0	5.5	7.0	1.7	3.5	7.0	1.7	1.5	5.0	1.2
Aug. 1	8.5	0.5	0	0.5	0.5	0	0	0	0	0
Aug. Sep. 28	4.0	0	0	0	0	0	0	0	0	0
Total	50.5	80.0			52.0			34.0		

average weekly growth as % of year's total.

growth for each period as % of year's total.

actual growth in cm for each period measured.

Table 8. Continued.

(ii) Desmoschoenus spiralis

1971	weeks	plant a cm	yr%	wk%	plant b cm	yr%	wk%	plant c cm	yr%	wk%	plant d cm	yr%	wk%
Oct. 10-Dec 18	14.0	34.5	66.0	4.7	32.5	81.0	5.7	6.0	27.0	1.9	5.0	31.0	2.2
1972 Feb. 10	7.5	10.0	19.0	2.5	7.5	19.0	2.5	5.0	23.0	5.1	3.0	19.0	2.5
Mar. 12	4.5	3.6	1.3	0	0	0	0	5.0	23.0	3.1	3.0	19.0	4.2
May 6	8.5	4.5	9.0	1.1	0	0	0	6.0	27.0	3.3	5.0	31.0	3.8
June 2	4.0	0	0	0	0	0	0	0	0	0	0	0	0
Total	50.5	52.6			40.0			22.0			16.0		

Note: no measurable growth in June, July, August.

Table 8. continued.

(iii) Raoulia australis

1971	Weeks	plant a cm	plant a yr %	plant a wk%	plant b cm	plant b yr %	plant b wk%	plant c cm	plant c yr %	plant c wk%
Oct. 10-Dec. 18	14.0	5.0	26.0	1.8	1.0	29.0	2.0	1.0	14.0	1.0
1972 Feb. 10	7.5	2.0	11.0	1.5	1.0	29.0	3.8	1.0	29.0	3.8
Mar. 12	4.5	5.0	26.0	6.0	0.5	14.0	3.1	0.5	14.0	3.1
May 6	8.0	4.0	21.0	2.6	1.0	29.0	3.6	1.5	43.0	5.3
Jun. 2	4.0	0	0	0	0	0	0	0	0	0
Aug. 1	8.5	0	0	0	0	0	0	0	0	0
Aug, 28	4.0	0	0	0	0	0	0	0	0	0
Total	50.5	16			3.5			3.5		

Growth increments of three species are summarised in Table 8, as absolute growth and percentage of total growth at each measuring time. Because the intervals are of varying length, the most useful comparative figure is that in the third column, giving the percentage of total growth per week (average), for the period concerned. From this it can be seen clearly which times of the year permitted most active growth (see sub-section (iii)).

Although much more investigation remains to be done, the results obtained are useful indications of the extremely slow growth rates.

(iii) SUMMARY OF PHENOLOGY

In Fig. 94 species have been arranged in groups according to their seasonal growth pattern, as follows:

Group (i). Bromus diandrus, Lagurus ovatus, Cerastium glomeratum, Silene gallica, Trifolium arvense. These are winter annuals, which germinate in autumn, and have their main growth period during winter. Cerastium and Silene die immediately after their brief spring flowering period, while the two grasses survive into early summer; Trifolium arvense is unusual in having a very extended flowering season into late summer, (although leaves wither much earlier).

Group (ii). Acaena ovina, Rumex acetosella, Hypochaeris radicata. These are perennial forbs, with a main growth phase in winter and a main flowering period in spring (small spurts of growth may occur at any time of the year following rain). Acaena novae-zelandiae also belongs in this group.

Group (iii). Lolium perenne, Poa pratensis, Anthoxanthum odoratum, Stipa variabilis, Poa laevis, Notodanthonia unarede. These are perennial grasses with main growth period from early to mid spring culminating in their flowering, followed by a resting period in summer; a slight spurt of growth occurs in autumn, followed by a resting period in winter. The forb Craspedia lanata follows the same pattern.

Table 6. Phenology of common indigenous species.

Species	seedlings appear	growth starts (perennials)	peak of growth	flower buds form	peak of flowering	seeds ripen (majority)	vegetative growth ceases	leaves fall or wither	plants die (annuals)
(a) Graminoids									
Desmo. spiralis	none seen	mid Aug.	Sep. Nov.	late Sep.	early Nov.	Jan.	April -May	NA	NA
Notodan. unarede	none seen	mid Aug.	early Sep.	mid Oct.	Nov.	Dec.	late Nov.	NA	NA
Poa lævis	none seen	mid Aug.	early Sep.	late Oct.	Nov. Dec.	Dec. Jan.	Dec.	NA	NA
Lovsia minima	none seen	early Sep.	Dec- Mar.	none seen	none seen	none seen	mid April	June	NA
(b) Forbs									
Acena nov.-zea.	early May	early May	June -Aug.	early Oct.	Oct- Nov.	Dec.	late Nov.	NA	NA
Calyst. sold.	none seen	mid Sep	Oct- Nov.	Nov.	Dec- Jan.	Jan.	Jan	April	NA
Crassed. lanata	April -May	Aug.	Oct- Nov.	mid Oct.	Nov.	Dec.	mid Dec.	Jan- Mar.	NA
Raoulia austral.	May June Aug.	early Sep.	Dec- Feb.	late Oct.	Nov.	Dec.	April	NA	NA
Scler. uniflor.	May June Aug.	early Sep.	Dec- Feb.	late Oct.	Nov.	Dec.	April	NA	NA
(c) Shrubs									
Carm. australis	none seen	mid Aug.	Sep- Nov.	late Sep.	Oct- Nov.	Nov- Dec.	late Dec.	NA	NA
Muehlen. complexa	none seen	mid Aug.	Sep- Nov.	Oct.	Nov- Jan.	Dec- Feb.	Jan.	June	NA
Pimelea prostrata	none seen	Aug.	Sep.	Aug.	Sep.	Nov.	Dec.	Jan. (some)	NA

NA=not applicable.

Table 7. Phenology of common adventive species.

Species	seedlings appear	growth starts (perennials)	peak of growth	flower buds form	peak of flowering	seeds ripen (majority)	vegetative growth ceases	leaves fall or wither	plants die (annuals)
(a) Grasses									
Stipa variabilis	none seen	mid Aug.	Sep.	early Oct.	early Nov.	early Dec.	early Dec.	NA	NA
Bromus diandrus	early May	NA	July	mid Oct.	Nov.	early Dec.	late Nov.	early Dec.	mid Dec.
Lagurus ovatus	early May	NA	July	mid Oct.	Nov.	early Dec.	Oct.	Oct.	Nov.
Anthoxan. odoratum	none seen	early Aug.	Sep.	early Oct.	Nov.	Dec.	Dec.	Jan.	NA
Lolium perenne	none seen	early Aug.	late Sep.	early Oct.	Nov.	Dec.	late Nov.	early Dec.	NA
Poa pratensis	none seen	early Aug.	late Sep.	early Oct.	Nov.	Dec.	late Nov.	early Dec.	NA
Aira caryophyll.	late Sep.	NA	Oct.	mid Oct.	Nov. Dec.	late Dec.	mid Nov.	late Nov.	Dec.
(b) Forbs									
Acaena ovina	early May	early May	June -Aug.	early Oct.	Nov- Dec.	Dec.	late Nov.	Dec. Jan.	NA
Hypochaer. radicata	early May	early May	Sep- Nov.	early Oct.	Nov- Dec.	Dec- Jan.	late Dec.	Jan.	NA
Rumex acetosella	early May	early May	June -Aug.	early Oct.	Oct- Nov.	Nov. -Dec.	Dec.	Dec- Jan.	NA
Trifolium arvense	early May	NA	June -Aug.	early Nov.	Dec.	Jan.	late Nov.	Dec- Jan.	Jan -Feb.
Cerastium glomeratum	early May	NA	July -Aug.	late Sep.	early Oct.	late Oct.	mid Oct.	late Oct.	late Oct.
	early May	NA NA	July -Aug.	late Sep.	early Oct.	late Oct.	mid Oct.	late Oct.	late Oct.

NA = not applicable.

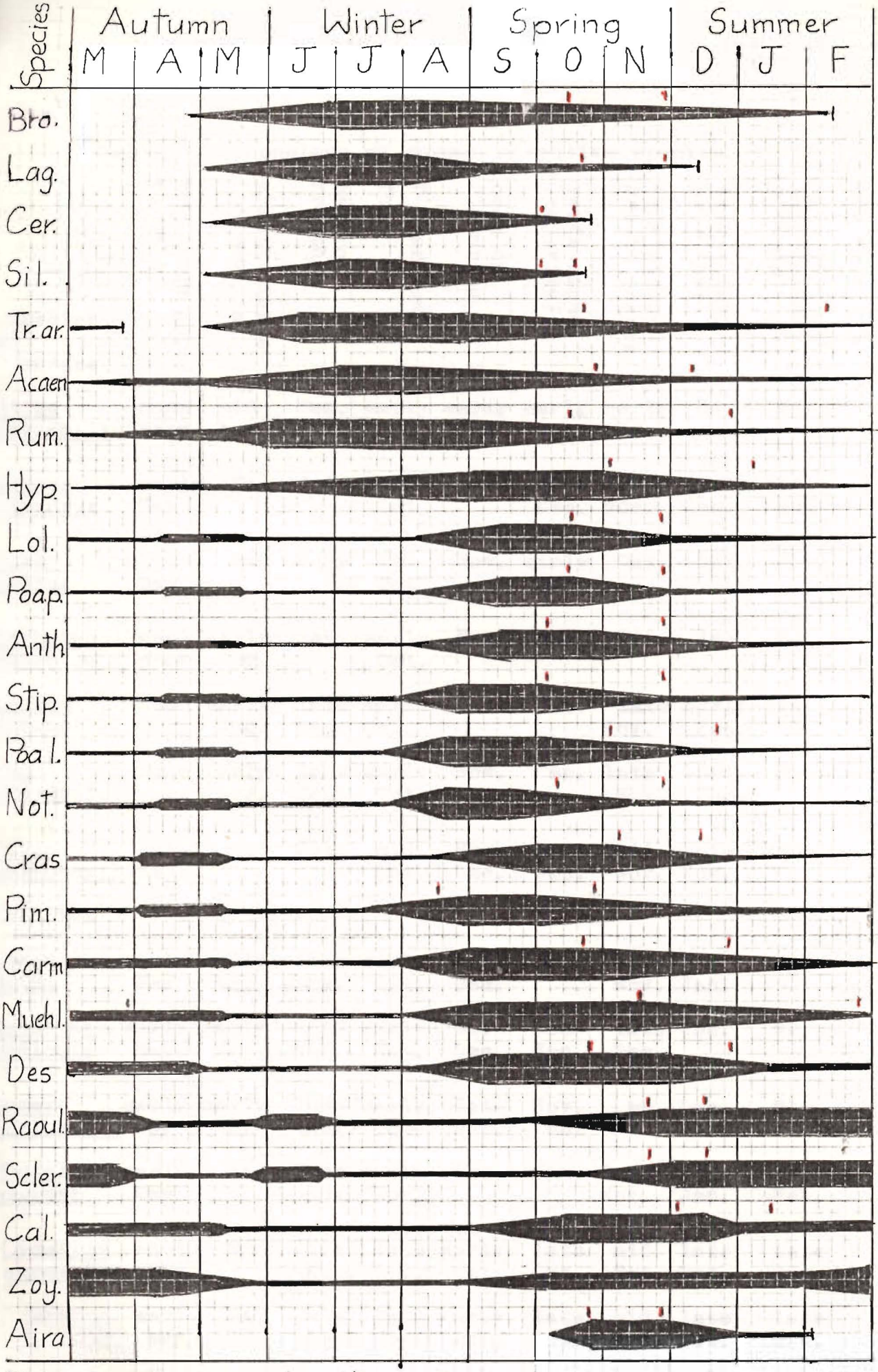


Fig. 94 Seasonal growth pattern of major dune species, 1971–1972
Thickness of black lines indicates comparative vegetative growth. Length of flowering period between red lines.

Group (iv). Pimelea prostrata, Carmichaelia appressa, Muehlenbeckia australis. These are shrubs with their main growth occuring from early spring to early summer and main flowering in late spring; some slight growth continues into autumn, and a few flowers are produced throughout summer, most markedly by Muehlenbeckia. Other species which can be included in Group (iv) are Myoporum laetum, Dodonea viscosa, Hymenanthera alpina, Clematis afoliata.

Group (v). Raoulia australis, Scleranthus uniflorus. These are perennial forbs with a long growing period, from late spring to late summer, and another small spurt of growth in autumn; they have a short flowering period from late spring to early summer.

Group (vi). Desmoschoenus spiralis, Zoysia minima. These are graminoids with a very long growing period, from early spring to late autumn.

Group (vii). Aira caryophyllea, Lepidium murale (not present in study area). These are summer annuals with a very short life-cycle, germinating in late spring, flowering within three or four weeks, and dying about mid-summer.

CHAPTER FIVE

RESPONSE OF PLANTS TO THE ENVIRONMENT

In response to the unusual set of environmental conditions in the Kaitorete dune system, there has appeared a unique group of plant species with special adaptations. All can be regarded as xerophytes, by the definition of Henkel (1946) viz "plants of dry habitats, able to adapt themselves successfully to the unfavourable influence of atmospheric and edaphic drought, by virtue of special morphological and/or physiological properties". To this should be added phenological behaviour, which is significant, especially in the case of the adventives.

Examination of the flora reveals an interesting mixture of indigenes, which have presumably evolved either on coastal sand dunes or on the shingle of dry river beds, and adventives which are characteristic of dry sandy or stony sites in their countries of origin, e.g. Stipa and Lagurus or else are species of wide ecological amplitude, e.g. Hypochaeris and Rumex acetosella.

In this chapter an attempt is made to relate the attributes of the different species, and the vegetation pattern, as described in Chapter 4, to the environmental conditions described in Chapter 3.

I. ATTRIBUTES OF THE DUNE SPECIES

1. MORPHOLOGY AND PHYSIOLOGY

(a) Aerial shoots. It has been pointed out by Stocker (1960) and others that such features of leaf anatomy as small cell size, and thick cell walls do not necessarily have any survival value for the plant, but are more likely to be the symptoms of an inherent, specialised metabolism by which the plant is able to survive water shortage. Beadle (1962) has postulated that similar anatomical features in certain sclerophyllous plants of eastern Australia are produced by a metabolism which has evolved in conditions of nitrogen and phosphorus deficiency.

However there are some xeromorphic features, commonly occurring among the dune species, which undoubtedly do aid plants in surviving drought. e.g. thick cuticle, especially with the addition of waxy or resinous substances, the presence of dense trichomes, rolling of leaves and complete or near-complete lack of leaves (associated with photosynthetic stems). Reduction of water lost in transpiration as a result of one or more of the above features has been demonstrated by Lemee, Zohary, and Evanari (ex Oppenheimer 1960).

Many xeromorphic features are apparently not only controlled by genetic constitution, but are actually intensified to some extent during the development of a plant in the conditions of a semi-arid environment. A series of experiments by Whitehead (1953 to 1963) demonstrated conclusively that reduction of shoot length and leaf size, increased proportion of veins, smaller cell-size and increased thickness of cell walls could all be produced by factors creating a high water tension in the cells during the plants' development, whether these factors were strong wind, low atmospheric humidity, or low soil water availability. This would seem to explain the high degree of plasticity shown by some of the species on the dunes.

e.g. Hypochaeris and Rumex here possess smaller and more rigid leaves than are found on the same species growing in moister situations; Discaria toumatou which here is restricted to one metre in height may grow up to 5m in more favourable habitats (c.f. Cockayne 1967). The writer noted that a specimen of Poa laevis transplanted to a moist garden environment produced long, lax, green leaves, in striking contrast to the shorter, stiff, brown leaves typical of this species on the dunes.

Although the productivity of the plants was not measured, there can be little doubt that the general vigour of plants on the Kaitorete dunes is reduced by the unfavourable water balance; but if water were adequate, growth would almost certainly be restricted by the low soil fertility. Willis and Yemm (1961) experimenting with turf transplants from dunes in North Devon, found that increasing the water supply made little difference to the plants, which retained their dwarfed character. But when the plants were supplied with a balanced mixture of N, P and K luxuriant growth ensued.

With regard to the adventive species xeromorphy is not a marked characteristic of their leaves (except in the case of Stipa and Ammophila); their leaves usually wither partially or completely at the onset of drought.

As in the case of morphology, physiological characteristics of xerophytes are in part genetically fixed, but are also influenced to a degree by conditions of the habitat in which the plant develops. Some of these physiological adaptations for drought resistance involve complex changes in the chemical nature of the cell protoplasm when the plant is subjected to water stress; this has been discussed at length by Stocker (1960) and by Levitt (1956). Such "drought-hardened" plants are very resistant to subsequent extremes of water deficit.

Whereas mesophytic species may be killed by even slight water saturation deficits in their cells, many xerophytes can withstand 60-80% WSD; exceptional cases occur (in some lichens and mosses) in which the plant can become over-dry without denaturation of its protoplasm, and can switch from dormant to active life with 24 hours (Oppenheimer 1960).

The shorn and stunted appearance of woody species growing on the dunes is apparently attributable to wind-borne salt, carried inland during S.W. gales. Wells and Shunk (1937) and Boyce (1954) have produced convincing evidence that necrosis and death of shoots on the seaward side is caused by salt entering the leaf tissue, possibly already damaged by sand abrasion.

The elorgated hummocks of Raoulia appear to owe their progressive decay on the S.W. side to the abrasive effect of moving sand, although salt may also play a part.

At this point some reference should be made to the variable growth forms of Carmichaelia appressa. Wall (1930) referring to the plant as C. subulata, noted three well-marked forms, i.e. prostrate mats, intermediate forms up to a metre, and erect forms up to two metres in height, adding that "the extreme prostrate form is of course due to wind pressure". Simpson (1945) rejected wind pressure as the cause of the prostrate form, noting that "branches point out in all directions". Wraight (1957) suggested that plants grew upright only where they were in competition with other species, and spread out horizontally in open situations.

It is my view that grazing may have considerable influence on the form assumed by the plants, since it is notable that the completely prostrate forms are those which have been severely affected by hares, rabbits, or stock nibbling the more accessible upper shoots (Fig. 65) while the upright forms (Fig. 66) are typically found either in the shelter of Muehlenbeckia clumps or on the dune area of Bayley's property which is protected by a stock fence.

However it is also possible that some of the forms are hybrids.

(b) Roots and Rhizomes. The tendency of underground parts of plants to develop according to an inherent pattern is more marked than is the case with aerial parts. Among the indigenous species of Kaitorete Spit certain distinctive features of the underground systems are obvious (Ch. 4, 5a ii).

There is a general tendency to develop absorbing rootlets at two levels, enabling the plant to take advantage of moisture in top few centimetres (from dew and light rainfall) as well as being able to draw upon water retained at deeper levels after the surface dries out.

For all species there exists a high root/shoot ratio, in some cases very pronounced, e.g. Raoulia. To account for this it has been postulated that the high rate of photosynthesis in the leaves, together with depression of shoot growth by various factors, results in the concentration of metabolites in the roots. This feature apparently serves as a great advantage for plants which have to cope with very low water and nutrient resources. Weaver (1958 a and b) writing about the plants of the Great Plains of North America; and Evanari (1962) in a study of the ecological problems of arid zones, have referred to the above features as characteristic of plants in arid habitats.

The development of unusually long and permanent root hairs, surrounded by agglutinated sand particles (as described for Desmoschoenus) has been noted in other species of dry sandy habitats by Killian (1942) who considered such root hairs adapted to remain functional during prolonged drought.

The presence of spongy "sleeves" like those described on the older roots of Carex pumila have been noted by Henrici (1929) on the roots of some South African grasses.

This feature is apparently due to the retention of the outer root cortex, the outer layers becoming corky while the inner ones become spongy. Killian (1942) and Lemée (1954) demonstrated the effectiveness of such "sleeves" in absorbing water from the soil by capillary suction.

Plants which have underground systems capable of indefinite horizontal extension e.g. Zoysia, Desmoschoenus, and Rumex acetosella and Carex pumila have a special advantage in being able to continually exploit new volumes of soil.

Of the grasses only Poa laevis produces root systems sufficiently deep and extensive to compete significantly with the tap-rooted species.

It is noteworthy that whereas all the indigenes have deep and/or extensive root systems, the adventives on the whole have comparatively poorly developed root systems (exceptions being Rumex acetosella, Acaena ovina and Hypochaeris radicata).

2. PHENOLOGY

(a) Vegetative activity. From Tables 8 and 9 and Fig. 94 it is apparent that for most species maximum vegetative growth occurs in winter and spring i.e. during the months of maximum soil moisture, lower temperatures and higher humidity.

It is to be noted that the species which grow throughout the winter are the adventives, which are presumably adapted to cool winter conditions in their countries of origin, whereas the indigenous species make little visible growth until spring. In a few cases leaves respond to the first hard frosts by withering e.g. Zoysia, Carex pumila, Calystegia soldanella and Muehlenbeckia complexa. Seedlings of Raoulia and Scleranthus provide exceptions, as their seeds germinate in June.

Species which are remarkable for their ability to continue vegetative growth through the hottest, driest months of summer are Raoulia, Scleranthus, and Zoysia; this ability was noted to a lesser degree in Muehlenbeckia complexa, Carmichaelia appressa and Desmoschoenus spiralis. As to be expected under conditions of such low water availability, growth rates for all species are slow.

The adventives respond to the onset of hot dry weather by dying completely, or else their aerial parts become shrivelled and they survive by means of their underground organs (e.g. Rumex, Hypochaeris and Acaena ovina). In this connection it is interesting to note that the leaves of the indigenous Acaena novae-zelandiae do not wither during drought periods, apparently an indication that it has a better water economy that its Australian relative, A. ovina.

(b) Reproductive activity. From Tables 8 and 9 and Fig. 94 it can be seen that the onset of flowering for different species is spread out from early spring to early summer, while a few continue on into late summer or even early autumn; seed production follows a similar pattern.

By means of this "staggered" reproductive activity, different species are making optimum demands for water and nutrients at slightly different periods, thus reducing competition. A remarkable feature of the annuals is their ability to reduce their vegetative growth, if unusually dry periods occur in winter, in order to divert essential metabolites to seed production. Thus it is common to see Lagurus, Silene and Cerastium plants only a quarter of their normal size but still bearing inflorescences.

The germination of the seeds of winter annuals has been shown to be dependent on the onset of cooler temperatures rather than on the presence of moisture, Went (1949). In an arid environment this ensures that seeds are not stimulated to germinate by spring and summer rains, since seedlings would inevitably be killed by subsequent dry conditions. Summer annuals on the other hand require warmer temperatures for germination; such species are not well adapted to the environment of the Kaitorete Spit, and they are notably few in number.

For germination of seeds of Raoulia, Scleranthus and Carmichaelia it appears that seasonal temperatures are not critical (since they were found to germinate in both spring and autumn) but a prolonged period of continuous moisture would seem to be essential.

The scarcity or absence of seedlings of many species which produce abundant seed has been noted, a fact almost certainly related to conditions of low soil moisture. Such species, if they lack any means of vegetative propagation, must depend on occasional years of favourable rainfall to maintain their populations (c.f. Went, 1955).

On all types of site except for the old dune area, even if conditions do favour germination, the mortality rate of seedlings is high. In the earliest stage "heat-girdling" of the hypocotyl must be a frequent cause of death, while sand abrasion, sand burial or deflation and

exposure of roots are likely to kill plants any time during their first or second year (as noted for Raoulia, Scleranthus and Craspedia seedlings on the blowout).

The reproductive potential of several species is reduced by animals feeding on inflorescences, as noted in the case of the palatable grasses and also Acaena ovina. The failure of Lupinus arboreus and Cytisus scoparius to spread may be attributed to the close "trimming" of mature plants by stock. (Rosa rubiginosa and Ulex europaeus, occurring only at the eastern end of the Spit, are controlled by periodic spraying with weedicide).

Because of the uncertainty of sexual reproduction in such a rigorous environment, species which reproduce partly or entirely by vegetative means have a considerable advantage in maintaining and increasing their populations. Desmoschoenus, Zoysia, Pteridium and Carex pumila are excellent examples of the efficiency of vegetative propagation almost exclusively. Other very successful species which spread by subterranean organs as well as by seed dispersal are Rumex acetosella, Acaena ovina and Calystegia soldanella. All the perennial grasses can increase by tillers or rhizomes. Muehlenbeckia complexa can spread to a limited extent by forming root suckers. But other woody species have no means of vegetative propagation, a factor contributing to the precariousness of their continued survival.

Summing-up. The dume plants can be classified as follows, according to the means by which they are adapted to the environment:

(i) drought-escapers i.e. annuals which rely on completing their life cycle during the most favourable conditions of winter and spring, their seeds lying dormant during the most severe drought and heat.

(ii) drought-evaders i.e. species which are able to overcome the problems posed by low rainfall, heat and

low humidity by morphological specialization of roots and shoots.

(iii) drought-endurers i.e. species which can withstand extreme water saturation deficits in their tissues by means of physiological specialisation.

It is noticeable that most of the adventives belong in group (i), only a few being in group (ii), whereas the indigenes are all in group (ii) and (iii). The implications of this, in respect to vegetation patterns, are discussed in the next section.

II. PLANT DISTRIBUTION ON THE DUNES

1. ZONATION.

It has been shown that across the Spit variations occur in edaphic factors, climatic factors, salt spray and sand movement, these being correlated with topography and distance from the sea. Study of the vegetation has shown the existence of biotopographic units which change with distance from the sea. However there is no simple, regular pattern of environmental gradients and vegetation zonation from the shore landwards. The vegetation pattern seems to fit the description given by Martin (1959) of a dune spit in New Jersey, i.e. "a zoned mosaic, dominated by topographically determined environmental features". Relative to this however, it is noteworthy that whereas many dune studies stress the differences between solar and shade slopes, windward and lee slopes, the Kaitorete dunes show remarkably little difference in the vegetation of such contrasting aspects, presumably because of their low profiles and gentle contours.

As Colinvaux (1972) has pointed out, correlation of the presence of a particular organism with a particular set of physical factors may be quite fortuitous, and the idea of single limiting factors (c.f. Liebig's Law of the Minimum) is generally not valid. However, study of the situation at the Spit suggests that certain physical factors have in fact determined the distribution of the indigenous plants, producing plant groupings in equilibrium with the environment. With regard to the adventives, these come into the category of opportunist species, which have, for the most part, invaded disturbed inland sites; correlation of their presence with a particular set of physical factors is therefore likely to be fortuitous. As exceptions it is necessary to point out that a few adventives, e.g. Hypochaeris, Lagurus, and Rumex, have invaded undisturbed, but open indigenous vegetation, notably on the foredunes, where they must be regarded as fully adjusted to the environment.

In a few overseas dune studies, e.g. Marvel (1969) in Holland, and Moore (1971) in England, attempts have been made to correlate vegetation and environmental types, using computer analysis and much more comprehensive data than were obtainable in the present study. Bearing in mind the need for further investigation, the following suggestions are tentatively made with regard to the possible influence of environmental factors on plant distribution at the Spit.

(a) Foredunes.

The dominance of a single species, Desmoschoenus spiralis, can be attributed to the unfavourable factors of strong onshore winds, with associated sand movement, sand abrasion and salt spray, which effectively exclude less hardy species, with the notable exception of Hypochaeris, (whose wide ecologic amplitude belies its somewhat mesophytic appearance). Water and nutrients, although low, are unlikely to be limiting for plants with extensive root systems, and a combination of root and shoot characteristics similar to that described by Marshall (1965) apparently enables Desmoschoenus to flourish in conditions of continuous sand deposition.

(b) Rear dunes.

Here the plants are less exposed to the effects of salt spray and sand abrasion, the substrate is more stable, marginally more fertile, and has slightly improved water-holding capacity. The indigenes Muehlenbeckia complexa, Carmichaelia appressa and Pteridium esculentum predominate. All have deep and/or extensive root systems while their aerial parts are adapted to exposure, the first by its dense, divaricating growth form and shedding of leaves in winter, the second by its prostrate form and almost leafless state, the third by sclerophylly and stomatal regulation of transpiration (Tinklin and Bowling 1968). Some Desmoschoenus persists, less vigorous than on the foredune; presumably there is insufficient sand deposition to provide the stimulation necessary for adequate new root development (Marshall, 1965). The annual grasses Lagurus and Bromus diandrus grow luxuriantly in association with the shrubs,

perhaps favoured by lower evaporation rates and some accumulation of organic matter at the soil surface. The perennials Hypochaeris and Rumex acetosella, both with wide tolerance ranges for moisture and nutrients, can survive, but conditions seem unfavourable for other adventives. The low calcium carbonate content of these dunes, and moderately acid conditions, help to explain the presence of Rumex acetosella which is well known as a calcifuge species. The presence of scattered specimens of Myoporum laetun, Dodonea viscosa and Sophora microphylla on some rear dune sites indicates that these species, possibly much more common in the past, are adapted to prevailing conditions, presumably by their xeromorphic leaves, compact growth form and extensive root systems.

(c) Old Dune Area.

This type of site is the least affected by onshore winds; it has improved soil fertility in the surface horizon, due to the admixture of humus and silt, which also increase W.H.C. - (though tending to offset this is the increased resistance to wetting and gravel in the profile). Although minimum air and surface temperatures are lower than at the other sites in winter, cold is unlikely to be a limiting factor for any species; the high summer temperatures and low humidity typical of other sites during summer are here modified by the more complete vegetation cover. These favourable factors account for this type of site supporting the greatest variety of species and the most dense vegetation cover - at least where disturbance due to fire and grazing has not been too severe (see 2 of this section).

(d) Blowouts.

These flat gravelly areas immediately behind the foredunes constitute a special type of site, replacing the "slacks" described in most dune systems (c.f. Ch.1.) The soil moisture regime is slightly more favourable than at all other sites (except for the old dune area during winter and spring). But unfavourable factors are the constant exposure to high winds,with accompanying sand movement and salt spray effects, high evaporation rates and high surface temperatures in summer. These factors make it an unfavourable

habitat for all but a handful of highly specialised indigenous species. Initial colonisers are Pimelea olivacea (on stones), Raoulia australis and Scleranthus uniflorus. The two latter, being "cushion plants", are well-adapted to survive in such an exposed site by reason of their growth habit and the efficient protection of their leaves by dense trichomes or thick cuticle, while their seedlings have the advantage of extraordinarily rapid root elongation. Although old plants eventually succumb to sand blast, and seedling mortality is high, their prolific seed production seems to ensure adequate replacement. The grass Zoysia minima and the sedge Carex pumila are other early colonisers here, adapted by their rapidly spreading rhizomes to exploit a large area for water and nutrients, while their low stature and sclerophyllous leaves withstand strong winds, sand abrasion, and a certain amount of sand burial. Desmoschoenus sometimes establishes itself here by seedlings, which seem to require more water than is available on the surface of the dunes. Around the periphery of the blowout, where run-off from the dunes is likely to provide a slightly more favourable water regime, and wind exposure will be lessened, conditions are suitable for Carmichaelia appressa, Poa laevis, Craspedia lanata and the hardiest adventives to become established.

(e) Sandy flats.

These sites, beyond the rear dunes, appear to be older blow outs. An admixture of silt and humus provide slightly improved W.H.C. and slightly higher fertility in the upper horizon. These factors, together with protection from onshore winds and negligible sand movement, provide conditions suitable for a number of other species in addition to those mentioned on the younger blowouts, notably Pimelea prostrata, Hymenanthera alpina and Muehlenbeckia complexa, all sclerophyllous shrubs with deep tap roots. These sites appear to have been much modified by fire, with subsequent invasion by adventives. There is no distinct line of demarcation between this type of habitat and that described as the old dune area, and any number of intergrades of vegetation occur.

2. SUCCESSION.

The type of dune succession described by Cowles (1899), in his classic study of the Lake Michigan area, can be expected only where the shoreline is retreating, leaving successively younger lines of dunes. This clearly does not apply at Kaitorete. As stated in Ch.1, the shoreline in the vicinity of the study area is thought to have been stable for a very considerable time, and it is possible that the topographic features may have existed for upwards of a thousand years in much their present form, except for periodic blowouts. It is presumed that the earliest dunes, (probably not much higher than some of the existing remnants) were formed in what has been described as the old dune area; as more sand became available from the shore, more seaward dunes were built up, under the influence of colonising plants of Desmoschoenus. As the younger dunes provided some protection for the older dunes, succession would have occurred on the latter as conditions became favourable for the establishment of species requiring surface stability. But after these early successional changes, the vegetation may have remained relatively stable until the time of Polynesian settlement (see 3 of this Section).

It is debatable to what extent the dune plants themselves may have been able to promote succession by modifying their environment, apart from the obvious initial stabilising of sand by Desmoschoenus. In an area like Kaitorete, low rainfall, low humidity, and low W.H.C. of the substrate result in soil development being arrested at an early stage, the vegetation is restricted to low-nutrient-demanding species, which tend to perpetuate the condition of low soil fertility, are of low stature, and provide only minimal shade (c.f. Olson 1958). The above considerations preclude succession to the relatively dense coastal forest, comprising mesophytic and high-nutrient-demanding species, of the kind typical of stabilised dunes on many parts of the South Island coast. However it is probable (see section 3 of this Chapter) that the climatic climax would be represented by sclerophyllous scrub or "dry" forest,

analogous in some respects to communities of woody species found in similar semi-arid habitats of other parts of the world, e.g. the Mediterranean "maquis" and the Australian "mallee". (c.f. Eyre, 1966).

The Clementsian theory of successional changes, culminating in a climatic climax has long been held generally untenable; even the more recent modifications of the theory seem less applicable to the Kaitorete situation than suggestions by Colinvaux (1972). He questions the existence of discrete climax communities, and explains succession simply in terms of vegetation proceeding towards the most stable physical structure and maximum biomass which can be supported by the physical environment, a condition generally associated with displacement of opportunist species by equilibrium species, and the development of a closed nutrient cycle. From the remnants of indigenous vegetation which still remain intact on the older, stable dune sites at Kaitorete, the above would appear to be an adequate explanation for the vegetation pattern as it existed prior to human interference. (See Section 3 of this Chapter.)

Subsequently repeated fires, and more recently the impact of grazing animals, have resulted in the depletion of much of the indigenous vegetation, and even its complete removal in some areas, followed by secondary succession. This has involved varying degrees of invasion by adventive herbs (mainly annuals or short-lived perennials) or in the latter case reversion to an early seral stage comprising much bare ground, considerable areas covered only with lichen, and scattered Raoulia plants, where there was formerly a fairly dense cover including woody species. Watt (1957) and Ranwell (1960 b) have described similar changes in reverse on dunes in Breckland and Anglesey, following the removal of rabbits by Myxomatosis. The establishment of Stipa variabilis in these strongly modified old dune areas is noteworthy; in similar semi-arid habitats in other parts of the world Stipa-dominated pasture forms a stable (and presumably climax) community, (c.f. Williams, 1956). However the species established at

Kaitorete is one of the less vigorous members of the genus, and would be unlikely to compete successfully with the deeprooted, indigenous, woody species, if the grazing factor were removed.

In the blowouts there are indications of succession, with increasing amounts of Zoysia and Carex helping to stabilise the surface. In the absence of grazing and trampling animals it is likely that more Desmoschoenus would become established, together with shrubs such as Pimelea prostrata and Dodonea viscosa (already present in some instances).

Reference is appropriate at this point to the findings of Wraight (1957). His vegetation analyses were made along transects across the Spit, one being at the eastern end (where dunes are non-existent), one near Bayley's homestead, and one near the western end - these last two in places where the sandy flats and old dune area have been much more strongly modified than in my study area. In consequence, close comparisons of the vegetation and habitats described in his study and mine are not possible, except in the case of the foredunes. It is noteworthy that he refers to "depleted arid zone succession" at the eastern end, but also speaks of "signs of regeneration", including "vigorous Poa with many young seedlings" - a description that hardly seems justified at the present time.

The purpose of his study was to compare the effect of different grazing treatment on three separate properties along the Spit. His general conclusion was that replacement of the indigenous shrub-tussock vegetation by adventive annuals or short-lived perennials was induced in direct proportion to the stocking intensity - a view confirmed by my observations.

3. THE VEGETATION PRIOR TO POLYNESIAN SETTLEMENT.

Because of the unique combination of environmental factors existing on the Spit, it is worth while attempting to assess the natural vegetation potential of the area. This involves a hypothetical reconstruction of the vegetation as it might have been about 900 years ago, before Polynesian settlement. From then onwards fire is likely to have played an important modifying role (Cumberland, 1962; Molloy et al, 1963; Molloy, 1969). That the Maoris used the area extensively as a food source is evidenced by the many piles of oven stones (there is also known to have been a Pa in the vicinity of Taumutu and one on the cliffs above Birdlings Flat). Fires fanned by strong winds would have quickly spread through the dry grass and scrub, probably leaving only the most seaward dunes and blowouts unaffected.

The following points need to be considered:

(i) At present even the least disturbed communities on the old dune sites (as at E) appear to be no more than deteriorating remnants of a formerly more varied and vigorous vegetation. The continued existence of even these remnants of the original vegetation is due only to a comparatively light stocking rate; the rapid acceleration of the destructive process that accompanies more intensive stocking is well illustrated further west, where a complete transformation, to shrubless short pasture of predominantly adventive species, has occurred.

(ii) The existence of isolated specimens of Dodonea viscosa, Myoporum laetum, Sophora microphylla, and Coprosma propinqua (described in Ch 4, 1, b) raises the question of how widespread these indigenous woody species may formerly have been. Climatic and edaphic conditions apparently are not too unfavourable for them to grow, and even to attain considerable size (note one specimen of Dodonea 5 m tall). All these species have been observed to set seeds; and Banks Peninsula must long have provided a ready source of seeds of these, and possibly other suitable

species such as Leptospermum ericoides. The above points strongly suggest that the existing specimens are in fact relics, which by chance escaped destruction by a series of fires that gradually eliminated a much greater population of large woody plants. It is probable that the Maoris would have cut down many trees to fuel their cooking fires, and cattle could easily have accounted for the final destruction of many smaller or fire-damaged specimens during the past hundred years.

(iii) The presence of many weather-worn and charred branches (up to 5cm diameter) scattered over the old dune area, indicates that some time within the last fifty years there must have been shrubs or small trees larger and more abundant than the existing bushes of Hymenanthera and Discaria (no more than a metre in height).

(iv) Exotic trees are able to grow to a considerable size in this environment, if introduced as established plants. In the old dune area near Birdling's western boundary is a solitary specimen of Pinus radiata (Fig. 50) over 15m in height and with a trunk about 60cm in diameter (it is probably about 80 years old). In the vicinity of Bayley's house, specimens of Cupressus macrocarpa, planted as a windbreak about 60 years ago, have reached a height of over 8m. Many hundreds of young pines (P. radiata) planted on the lee side of dunes near Bayley's homestead (Fig. 8) have grown about 30cm per year over 6 years, without any attention except being fenced off from stock.

(v) Although no really early descriptions of the vegetation of the Spit are available, the comments of Wall (1930) provide a few clues. His account being fairly superficial generally gives no idea of the abundance of species populations, but he refers to "Poa caespitosa (now P. laevis) dominant over the greater part of the area except close to the sea", so we are left in no doubt about the marked decline of this species, which at present has only a scattered population, most of the tussocks showing signs of deterioration. Mention is made of "strong cushions of

Pimelea laevigata (now P. prostrata) growing in the dune hollows", suggesting that this species too has declined during the past forty years. Of his species list, the only plant now entirely absent is Phormium tenax, mentioned as "present on the dunes, though scarce".

(vi) The age of the dune system (see Ch.1) indicates that before Polynesian settlement, sufficient time had elapsed to allow the development of climax vegetation. Olson (1958) postulated that under "normal succession" at Lake Michigan soil conditions would have continued to improve for about 1000 years, being associated with the attainment of climatic climax vegetation.

(vii) Climate change could well have been a factor contributing to the virtual disappearance of native trees from the Spit. Using as evidence the lack of regeneration of podocarp species, Holloway (1954) suggests that since the 13th century there has been a general change to cooler, drier climate in the South Island. Wardle (1963) has produced evidence of a "regeneration gap" in podocarp stands, dating from about 1300, with a period of minimum regeneration between 1300 and 1800; he suggests that the cause of this was most likely a worsening of the water regime, acting on seedling establishment. As might be expected, such effects seem to have been most notable on the drier eastern side of both islands. It can be seen from Appendix II, Tables 17, 18, that short-term fluctuations of climate in Canterbury have been a feature of the past 80-90 years. When rainfall has remained below the average for periods of five to ten years, suppression of seedling establishment may well have proved critical for species whose numbers were already much depleted.

The points outlined above provide clues which, together with a knowledge of the environmental factors prevailing in recent times, form the basis for the following description of the probable floristic composition and physiognomy of the pre-Polynesian dune vegetation:

(a) Foredunes.

The primitive appearance of the most seaward dunes was probably little different from what it is today except for the absence of the adventives Hypochaeris and Lagurus.

(b) Rear dunes (i.e. second line of dunes).

Before the impact of fires, these dunes probably carried a more complete cover of Muehlenbeckia complexa and Carmichaelia appressa than is now present, while Calystegia soldanella and Rhagodia triandra (both palatable to stock) are likely to have been more abundant. In interdune hollows may have been considerably more Dodonea viscosa, Myoporum laetum, Sophora microphylla and Coprosma propinqua than now, together with Phormium tenax and Cortaderia species (both of which are likely to have been eaten out by stock soon after the land was taken up for farming).

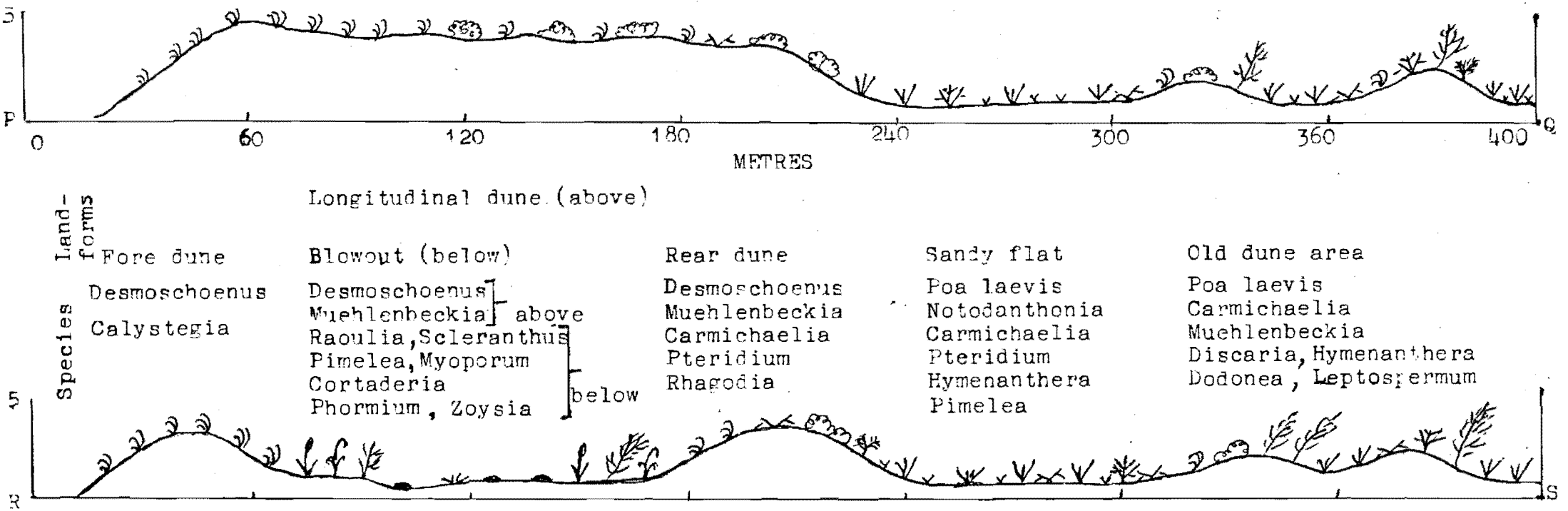
(c) Old Dune Area.

A broad strip along the middle of the Spit can be envisaged as carrying a multi-storeyed closed community. Poa laevis would have formed the dominant cover, (the tussocks more vigorous and taller than at present). At ground level, in spaces between tussocks, would have been considerably more of the palatable herbaceous indigenes such as Vittadinia australis, Dichondra repens, Convolvulus erubescen, Carmichaelia corrugata and Notodanthonia unarede, plus patches of moss such as Hypnum cupressiforme and Triquetrella papillata (the last likely to have been less abundant than now, since its present extensive distribution, as with Parmelia conspersa, is probably due to lack of competition). Stands of Scirpus nodosus, Pteridium esculentum and Carmichaelia up to 1m high would have been common, together with the declining Desmoschoenus spiralis. Low shrubby forms (up to 2m high) would have been scattered through the tussock e.g. Hymenanthera alpina, Clematis afoliata, Coprosma propinqua, Discaria toumatou. A tree layer comprising still more widely scattered specimens would probably have included Dodonea viscosa, Myoporum laetum, Sophora microphylla and Leptospermum ericoides - these up to 5m in height.

(d) Blowouts.

These areas may have appeared little different from the way they do today, although the species mentioned would have been

Fig.95.HYPOTHETICAL PROFILE OF STUDY AREA REPRESENTING PRE-POLYNESIAN VEGETATION.
(along transects PQ, RS, as in Fig.5.)



Scale 0 —— 30 m Vertical exaggeration x 6.

KEY: Desmo. Muehlen. Carmich. Poa laevis. Phormium. Cortad.
Raoulia Pimelea Hymen. Copros. Discaria, Myoporum. Pteridium. Notodan.
Dodonea, Leptosp.

(plants not to scale)

more abundant in the absence of trampling and grazing animals. Phormium, Cortaderia, and a few shrubs probably became established with the passing of time.

(e) Sandy Flats.

These areas would have been less extensive before the old dunes became eroded. The existing indigenous species (with the exception of Raoulia, Scleranthus and Parmelia) would have been more abundant, providing a fairly complete ground cover, with some stratification.

Fig. 95 represents an hypothetical profile of the above communities, along a transect from foredunes to oldest dunes (c.f. Fig. 5 which represents a profile of existing communities).

CHAPTER SIX

GENERAL DISCUSSION AND CONCLUSIONS

The foregoing account has served to highlight the unusual and in some cases unique features of the dune system at Kaitorete, as summarised below:

(i) The combination of climatic extremes (low rainfall, high temperatures in summer and comparatively low ones in winter, strong winds and low humidity) is unusual for a coastal dune area in these latitudes. Most other dune systems that have been described in temperate latitudes have higher rainfall, higher humidity, and less extreme temperature fluctuations.

(ii) The sand is much coarser than in most dune systems. This factor contributes to the long-standing stability of the system. The problem of low rainfall is also aggravated by the low WHC of the substrate, and only xerophytic plants can survive.

(iii) The presence of a gravel basement beneath the sand has important implications, accentuating the problem of low water availability for plants, and notably resulting in the absence of wet dune slacks which are a feature of most dune systems. Factors (ii) and (iii) together account for the fact that many of the indigenous species present are more typically found on inland sites such as dry gravelly river beds.

(iv) The region is one of the increasingly rare instances in New Zealand, (and indeed throughout the world) where coastal dunes have remained relatively undisturbed by human activities, and consequently retain much of their indigenous vegetation, which in this case is all the more interesting because many of the species are endemic to New Zealand.

(v) The dominance of the sand-binder Desmoschoenus spiralis, and its influence on dune form, is of particular

interest. This endemic plant, formerly common on dunes all round New Zealand, has now been almost entirely replaced by the introduced and cosmopolitan species Ammophila arenaria, which was planted extensively in the late 19th and early 20th centuries, to arrest erosion after Desmoschoenus had succumbed to the impact of fires and grazing. Desmoschoenus was described by Cockayne (1911) as "a sand-binder par excellence". He noted that its ability to produce extensive rhizomes down-slope results in gently contoured low dunes which resist undercutting by wind, in contrast to Ammophila, which by reason of its taller, clumped habit of growth, builds higher, steeper dunes in which undercutting is liable to occur, initiating blowouts. Esler (1970) is in agreement with this, although he comments on the superiority of Ammophila as a rapid stabiliser of dunes which have started to erode through removal of their primitive vegetation.

(vi) As a result of the rigorous environment produced by climatic and edaphic factors, natural selection operating over a very long period has brought into existence a vegetation which is floristically and physiognomically unique. The indigenous species exhibit a fascinating variety of morphological adaptations to drought, wind and low soil fertility. Their physiological adaptations, which still await investigation, are likely to be equally intriguing. In this connection it is suggested that the nitrogen-fixing species Carmichalia appressa is likely to play a key role in improving soil fertility, but Discaria toumatou and doubtless several other species may also contribute.

The list of adventive flora shows that natural selection by the environment has sorted out only those species which were preadapted to the harsh conditions. They are either species of wide ecological amplitude, or species which have originated in similar semi-arid habitats overseas.

(vii) The indigenous vegetation of the Spit comprises species of diverse morphology and ecological behaviour, which

are complementary in their utilisation of the available resources. The component species are all perennials, many very long-lived, and because of their low nutrient demands, coupled with a high degree of morphological and physiological specialisation, they are well suited to maintain permanent vegetation cover.

In striking contrast to the complex and relatively stable indigenous vegetation which formerly covered the old dune area, the existing large areas of induced vegetation are much less complex, comprising only herbaceous species, either annuals or relatively short-lived perennials. Nearly all the adventive species are comparatively shallow-rooted, exploiting only the upper 30 cm or so of soil, so that competition for water and nutrients is intense, and the cover necessarily remains sparse.

It seems inevitable that, under the continuing impact of introduced animals, the indigenous vegetation of the Kaitorete dunes will sooner or later be entirely replaced by adventives, which are adapted to the grazing factor by virtue of their short life-cycles and prolific reproduction, whereas the indigenes are unable to replace themselves under these conditions. Observations suggest that the long-term result is likely to be a vicious circle of declining soil fertility and continuing deterioration of plant cover, with eventual erosion of bared surfaces.

Evidence from dune areas throughout the world emphasises the drastic changes which can occur within a relatively short space of time when disturbance of a natural ecosystem goes beyond a certain point. It is noteworthy that on most of the New Brighton dunes today it is difficult to find any indigenous species, whereas at least 38 flourished there only sixty years ago (Pegg 1913). All the way up the east coast from Christchurch to Blenheim the dunes reflect a similar state of floristic impoverishment. It might be possible to forestall erosion at Kaitorete by planting the whole dune area with Ammophila arenaria, Lupinus arboreus and Pinus radiata, as has already been done extensively on

other New Zealand coastal dunes. However, the Kaitorete dunes have not yet reached, and may never reach, a stage where such drastic action is necessary. It seems probable that, if treated with care, much of the indigenous vegetation would be capable of holding its own, or even increasing in the long term, if not subjected to pressure from introduced animals. In such a delicately balanced ecosystem, where the physical environment is so exacting, one more unfavourable factor is bound to have adverse effects on the tenuous existence of the plants.

To what extent protection from further human interference might stimulate regeneration of the primitive dune communities is dubious, in view of the almost certain persistence of many of the well-adapted adventive species, and the possible occurrence of short- or long-term unfavourable climate changes. Nevertheless, a strong case exists for excluding grazing animals from at least a part of the Kaitorete dune system. If set aside as a botanical reserve it would provide a valuable opportunity for future research into the complex checks and balances operating in a near-natural ecosystem that has many unique attributes.

SUGGESTIONS FOR FURTHER STUDY

The research outlined above has in many respects been no more than a pilot study. Investigations were of necessity spread over such a wide range that it was not possible to obtain as much detailed information as desirable. However, it has revealed the need for further, more intensive, studies, in the following aspects:

(i) the hydro-economy of the dune plants; transpiration patterns; utilisation of dew.

(ii) specific requirements for germination and seedling establishment.

(iii) growth rates of plants - using large numbers of replicates.

(iv) nutrient requirements of different species.

(v) role of micro-organisms, both endophytic and free-living, especially in relation to availability of nitrogen and phosphorus.

(vi) influence of grazing animals (using permanent enclosures over a period of several years).

(vii) influence of insects, especially the Lepidoptera.

(viii) sand movement, using a large number of traps.

(ix) infiltration and percolation of water through the profile - perhaps by trenching.

(x) measurement of humidity, temperature, and wind velocity and evaporation in microhabitats, using more sophisticated techniques and more instruments than were available previously.

(xi) soil chemical analyses at a number of depths in the different soil types.

ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisor, Dr. C.J. Burrows, for his patient guidance, encouragement, and constructive criticism; also to Dr. A. Dobson and Mr F.E. McGregor of the Botany Department.

Thanks are due to Mr A.E. Birdling and Mr O.P. Bayley for their co-operation and permission to conduct the investigation on their properties; also to relatives and friends for occasional assistance in field work.

APPENDIX I

SOIL DATA

Table 1. Particle size analysis of soils at microstations from 125 ml samples at each of three depths.

	% wt. of sample*			
	>2.0 mm	2.0-0.2 mm	0.2-0.07 mm	<0.07 mm
Station A				
0-10 cm	NIL	94.8	5.0	0.2
20-30 cm	"	94.8	5.0	0.2
40-50 cm	"	94.5	5.3	0.2
% total for profile	"	94.7	5.1	0.2
Station B	2.2	93.3	4.1	0.4
0-10 cm				
20-30 cm	5.5	92.7	1.7	0.1
40-50 cm	4.3	92.3	3.2	0.2
% total for profile	4.0	92.7	3.0	0.2
Station C				
0-10 cm	NIL	95.9	3.9	0.2
20-30 cm	"	89.8	10.3	0.9
40-50 cm	"	90.6	7.9	1.5
%total for profile	"	92.1	7.3	0.8
Station D				
0-10 cm	16.3	76.9	5.5	1.3
20-30 cm	14.0	77.0	6.6	2.3
40-50 cm	14.3	80.7	3.8	1.2
% total for profile	14.8	78.2	5.3	1.6
Station E				
0-10 cm	7.0	85.5	5.7	1.8
20-30 cm	38.0	55.8	3.9	2.3
40-50 cm	48.1	46.8	3.5	1.6
% total for profile	31.0	62.7	4.4	1.8

* Note stones >1.75 cm removed.

Table 2 a. Summary of chemical analysis of soils and WHC
(from Wraight 1957)

Soil	Kairaki Sand	Kairaki very stony brown sand	Waikuku brown loamy sand	Taumutu fine loamy gravel
Alt.	8.3-18.6 m	7.0-11.5 m	6.0-9.0m	7.0-8.5 m
WHC%	22	30	38	42
pH	6.3	5.6	5.5	5.6
% loss on ignition	0.91	2.6	5.3	0.16
% total N	0.025	0,08	0,16	4.3
C/N	21	20	19	16
% sol. salts	0.042	0.07	0.07	0.05

nearest to shore ←---------- ---- inland

sampled at 0-20 cm depth.

Table 2 b. Chemical analysis of soils
(from Burrows 1968)

Soil	Kairaki sand	Taumutu gravelly sandy loam
pH	5.4	5.8
P mg/l	15	20
C%	1.2	3.2
N%	0.08	0.28
C/N	15	11
BS%	34	56
CEC me%	5.0	13.7
TEB me%	1.7	7.7
Ca me%	1.7	5.6
Mg me%	0.6	2.5
K me%	0.55	2.2
Na me%	-	-

sampled at 0-15 cm depth.

Table 3a. Soil moisture % (wt.) at microstations.

19 May, 1971 - 1 April 1972

1971	Stn.A			Stn.B			Stn.C			Stn.D			Stn.E		
	BD	i	ii	BD	i	ii	BD	i	ii	BD	i	ii	BD	i	ii
May 19	1.1	39	-	1.3	29	-	1.3	24	-	1.3	31	-	1.1	54	-
	1.1	38	-	1.4	30	-	1.3	08	-	1.3	48	-	1.3	63	-
	1.0	45	-	1.3	32	-	1.2	31	-	1.4	43	-	1.7	44	-
		44			30			24			44			53	
Jul 4	1.1	18	-	1.4	22	-	1.1	21	-	1.1	46	-	1.2	38	-
	1.1	29	-	1.3	35	-	1.2	23	-	1.1	64	-	1.1	50	-
	1.0	48	-	1.2	54	-	1.1	43	-	1.1	40	-	1.6	93	-
		32			37			29			50			60	
Aug 15	1.2	23	15	1.2	15	14	1.3	14	32	1.3	25	38	1.3	42	60
	1.2	25	28	1.3	26	23	1.3	26	37	1.1	42	47	1.2	60	52
	1.3	34	31	1.3	26	35	1.2	35	39	1.3	25	35	1.5	36	15
		26			23			31			35			44	
Sep 1	1.1	30	35	1.3	23	24	1.1	20	43	1.2	40	33	1.2	107	142
	1.1	40	35	1.1	28	15	1.1	11	26	1.1	49	46	1.2	47	141
	1.3	48	44	1.1	50	44	1.1	16	32	1.1	52	42	1.1	85	47
		38			37			25			44			79	
Nov 15	1.3	16	18	1.1	21	27	1.3	13	10	1.3	12	41	08	120	85
	1.3	38	39	1.1	37	49	1.2	61	64	1.3	41	60	1.2	95	78
	1.3	41	42	1.1	48	47	1.1	57	57	1.5	15	39	1.6	31	27
		32			38			36			35			79	
Dec 9	1.3	00	04	1.2	05	04	1.1	00	00	1.1	07	01	1.0	13	13
	1.2	05	18	1.1	26	16	1.3	07	10	1.5	14	17	1.3	24	18
	1.3	15	21	1.3	31	27	1.3	12	10	1.5	15	20	1.5	12	18
		11			18			07			12			16	
Dec 27	1.2	27	10	1.3	31	24	1.1	25	15	1.3	27	20	09	65	61
	1.3	12	13	1.3	36	29	1.3	18	29	1.2	43	47	1.1	22	15
	1.1	32	31	1.1	17	21	1.3	24	20	1.1	21	22	1.6	13	13
		21			26			22			30			33	

continued over

NOTE:

BD=bulk density of sample

i and ii represent duplicate samples at each station.

For stations A,B,C and D all samples were taken from beneath a bare surface;for station E sample i was taken beneath a bare surface and sample ii beneath a moss-covered surface.

For measurements on each date:

line one represents % value at depth 0-10 cm,

line two represents % value at depth 20-30 cm,

line three represents % value at depth 40-50 cm,

line four represents % value for whole profile, (ie.from sum of samples at 3 depths,averaged).

Table 3a. continued

1972	Stn.A			Stn.B			Stn.C			Stn.D			Stn.E		
	BD	i	ii	BD	i	ii	BD	i	ii	BD	i	ii	BD	i	ii
Jan	1·2	0·5	1·5	1·3	1·9	1·4	1·2	1·8	0·9	1·4	0·9	1·4	1·2	1·5	4·8
9	1·3	5·4	4·6	1·4	3·2	3·7	1·3	4·1	2·2	1·5	4·4	3·7	1·2	7·2	2·8
	1·3	4·4	4·1	1·4	4·9	4·8	1·2	1·9	4·1	1·5	2·2	3·1	1·6	5·7	4·5
		3·4			3·3			2·5			2·9			4·8	
Feb	1·2	0·6	1·0	1·5	2·2	2·5	1·2	1·0	3·2	1·3	2·9	4·2	1·2	1·9	5·0
10	1·3	3·2	4·0	1·5	3·4	4·6	1·3	6·3	5·2	1·2	5·2	4·6	1·3	6·3	1·3
	1·3	3·5	4·5	1·4	2·9	3·9	1·3	4·9	4·1	1·5	3·7	3·6	1·4	5·3	1·5
		2·8			3·3			4·1			4·0			4·5	
Feb	1·1	0·5	-	1·4	1·3	-	1·2	0·0	-	1·3	0·6	-	1·2	1·9	-
28	1·2	1·3	-	1·3	2·4	-	1·3	1·5	-	1·1	2·0	-	1·3	3·1	-
	1·3	1·4	-	1·4	2·7	-	1·2	1·5	-	1·5	1·5	-	1·6	2·4	-
		1·1			2·1			1·0			1·4			2·5	
Mar	1·2	1·0	-	1·3	0·7	-	1·1	0·3	-	1·3	1·5	-	1·1	0·3	-
12	1·2	1·5	-	1·4	3·7	-	1·2	1·9	-	1·2	2·8	-	1·4	1·8	-
	1·3	1·5	-	1·4	2·0	-	1·2	1·9	-	1·5	4·0	-	1·7	1·3	-
		1·3			2·1			1·4			2·8			1·1	
Apr	1·2	1·1	-	1·2	1·8	-	1·3	1·4	-	1·3	1·1	-	1·0	5·5	3·0
1	1·1	2·8	-	1·3	3·8	-	1·2	2·0	-	1·2	3·1	-	1·4	3·1	2·4
	1·2	4·3	-	1·3	4·4	-	1·4	5·3	-	1·5	3·1	-	1·6	2·3	2·0
		2·7			3·3			2·9			2·4			3·1	

Table 3b. Soil moisture at stations D and E, 13 Aug. 1972, sampled in quadruplicate.

	soil moisture % (wt)			
	Stn D			
Depth (cm)	i	ii	iii	iv
0-10	1.9	1.5	2.8	3.1
20-30	3.5	4.2	3.4	4.1
40-50	3.5	2.8	3.0	2.5
	Stn E			
0-10	9.0	7.4	9.6	8.1
20-30	4.2	4.3	6.9	5.4
40-50	3.0	2.8	4.5	3.6

Table 4 a. Sand movement at microstations A, B, C and D, Dec 1971-June 1

Volumes (ml) collected in traps (a) at surface,
(b) at 8-15 cm height.

Period measured	Station A		Station B		Station C		Station D	
	a	b	a	b	a	b	a	b
10 Dec. 1971- 10 Feb. 1972. 2 months	92	3	35	25	29	15	18	-
10 Feb.- 10 May 1972 3 months	93	10	58	60	67	50	25	-
10 May- 10 June 1972. 1 month	95	8	48	38	39	35	20	-
Total 6 months	285	21	141	123	135	100	63	-

Table 4 b. Particle size analysis of sand moved (a) at surface
(b) at 8-15 cm height
from sample collected 10 Feb. 1972.

(a) surface. % of total sample.

size class	Station A	Station B	Station C	Station D
> 1.0 mm	31	46	12	46
1.0-0.6 mm	41	37	47	33
0.6-0.2 mm	27	15	39	20
< 0.2 mm	2	1	2	1

(b) at 8- 15 cm height

> 1.0 mm	-	-	1	
1.0-0.6 mm	-	-	34	
0.6-0.2 mm	-	-	63	
< 0.2 mm	-	-	2	

* (samples from A and B inadequate- see Text)

APPENDIX II

CLIMATE DATA

Table 1. Temperatures (^{o}F, three levels) at microstations
Feb 1971 - Mar 1972

1971	A			B			C			D			E		
	as	s	bs	as	s	bs	as	s	bs	as	s	bs	as	s	bs
6 Mar															
max	78	80	77	80	82	77	85	87	78	82	79	74	86	85	72
min	55	50	65	48	50	65	47	44	62	43	45	66	38	40	62
12 Apr															
max	84	83	72	82	87	71	83	88	77	74	82	70	84	84	71
min	40	40	53	36	41	52	36	35	52	32	34	52	28	32	52
11 May															
max	74	76	63	75	80	65	83	77	71	75	77	63	76	77	63
min	37	37	48	34	36	48	32	32	48	30	32	48	26	30	48
6 Jun															
max	62	61	55	62	63	55	60	57	55	61	65	55	61	55	53
min	40	34	41	30	33	50	32	30	46	33	31	45	28	31	46
4 Jul															
max	60	59	54	60	59	54	60	57	52	60	63	54	60	58	53
min	30	30	39	27	28	38	30	26	38	32	23	36	20	25	40
1 Aug															
max	62	62	50	61	64	50	63	65	51	61	62	47	62	58	46
min	28	28	37	26	26	37	28	23	35	23	23	36	18	23	37
30 Aug															
max	65	68	56	68	69	58	68	70	58	67	68*	55	66	65	50
min	30	30	38	28	28	38	28	25	35	22	24*	37	19	23	38

continued over

NOTE:

Temperatures read from 10am to noon, E to A.

Intervals of 28 days.

as= air temperature 30 cm above soil surface.

s = temperature at soil surface.

bs = temperature 10 cm below soil surface.

* est.

Table 1. continued.

1971	A			B			C			D			E	
26	as	s	bs	as	s	bs	as	s	bs	as	s	bs	as	s	bs
Sep														
max	68	77	58	73	77	65	74	75	60	73	80	59	74	73	55
min	32	32	43	30	35	42	28	27	44	34	25	43	20	20	43
25															
Oct															
max	77	85	67	82	86	73	81	83	68	80	82	68	83	82	60
min	36	36	47	32	34	44	32	31	47	28	30	46	26	30	45
25															
Nov															
max	80	84	75	80	86	82	78	85	76	82	82	76	85	86	69
min	42	38	52	40	38	49	44	32	50	44	30	48	25	28	49
23															
Dec															
max	91	94	82	91	93	85	88	97	90	92	92	90	95	98	79
min	45	42	60	40	42	56	38	38	54	32	32	60	32	33	57
1972															
22															
Jan															
max	94	101	88	85	102	90	88	100	83	91	98	80	99	100	77
min	44	46	57	38	50	56	45	42	58	40	42	60	32	40	56
20															
Feb															
max	85	85	85	80	85	83	80	88	79	78	84	80	85	90	70
min	57	48	52	45	49	53	43	44	60	35	44	64	34	48	60
12															
Mar															
max	90	92	85	90	90	86	87	90	82	88	90	81	92	92	70
min	50	42	58	40	40	56	38	38	52	36	38	59	28	32	56

Table 2. Temperature and humidity at four microstations, Dec. 15-19, 1971.

	Stn A		Stn B		Stn C		Stn D	
Dec.15	RH %	T°F	RH %	T°F	RH %	T°F	RH %	T°F
N	58	75	56	73	50	85	555	72
4	58	78	50	78	50	80	52 76	76
8	60	66	57	70	80	66	60	66
MT	63	61	56	68	90	60	65	61
Dec.16								
4	63	59	54	67	94	58	65	58
8	63	61	54	66	86	61	64	60
N	58	69	54	66	60	71	58	68
4	60	68	56	70	50	78	58	68
8	63	58	64	66	84	62	64	58
MT	63	58	64	66	90	58	64	57
Dec.17								
4	63	57	64	66	90	58	64	57
8	63	62	64	66	84	63	64	60
N	59	70	55	68	54	81	60	67
4	59	76	48	72	56	80	59	72
8	61	66	66	69	76	66	56	68
MT	62	58	65	66	90	59	63	58
Dec.18								
4	62	57	64	66	94	55	65	55
8	60	68	60	66	90	65	63	66
N	58	78	53	72	52	90	56	74
4	56	86	44	82	52	86	48	80
8	61	66	48	78	58	75	50	72
MT	60	76	60	68	70	66	58	65
Dec.19								
4	59	74	55	66	66	64	50	63
8	58	80	45	70	60	72	48	72
N	48	95	32	88	36	90	38	88

NOTE: Humidities at stations A,B and D are unreliable at upper and lower extremes of their range; humidity at C appears to be fairly accurate.

Table 2 continued. Temperature and humidity at two microstations, Jan. 9-13, 1972.

	Stn A		Stn B	
Jan.9	RH %	T°F	RH %	T°F
N	46	72	40	72
4	50	68	48	70
8	55	60	70	58
MT	56	58	65	58
Jan.10				
4	58	56	80	54
8	50	68	58	64
N	44	82	40	80
4	52	75	58	75
8	57	70	70	70
MT	56	58	76	55
Jan.11				
4	56	58	76	55
8	54	58	74	58
N	50	64	52	64
4	50	65	54	66
8	54	58	66	60
MT	55	56	70	57
Jan.12				
4	56	57	78	54
8	50	66	58	66
N	47	76	46	76
4	50	74	56	70
8	56	65	78	64
MT	50	62	60	62
Jan.13				
4	48	63	50	63
8	49	68	50	68
N	46	70	46	70

NOTE: Humidities at A unreliable; humidities at B fairly accurate.

Table 2 continued. Temperature and humidity at two microstations, Feb. 21-25, 1972.

	Stn A		Stn D	
Feb. 21	RH %	T°F	RH %	T°F
N	55	74	66	70
4	58	64	80	72
8	60	59	90	62
MT	60	58	90	56
Feb 22				
4	60	60	86	62
8	58	62	75	63
N	54	72	62	70
4	56	68	68	72
8	60	60	88	62
MT	60	58	90	62
Feb. 23				
4	60	58	89	64
8	58	62	78	64
N	50	80	58	75
4	52	72	60	76
8	54	70	68	75
MT	60	60	91	70
Feb 24				
4	60	60	92	62
8	60	52	93	58
N	55	54	70	54
4	56	55	68	60
8	57	54	64	56
MT	60	50	88	55
Feb. 25				
4	62	49	92	52
8	62	44	80	44
N	45	70	45	70

NOTE: Humidities at A unreliable; humidities at D fairly accurate.

Table 3. Temperature and humidity recorded below Stevenson's screen, Dec. 23-27, 1971 and Feb. 21-26, 1971

1971			1972		
Dec. 23	RH %	T°F	Feb. 21	RH %	T°F
4pm	40	70		80	68
8	50	62		89	63
MT	77	58		89	62
Dec. 24			Feb. 22		
4	76	56		84	63
8	61	66		85	65
N	57	66		65	72
4	60	64		65	72
8	63	60		84	64
MT	87	53		89	63
Dec. 25			Feb. 23		
4	87	53		90	64
8	76	68		85	65
N	46	78		66	76
4	55	63		59	77
8	60	71		65	73
MT	65	64	Feb. 24	90	64
Dec. 26			Feb. 24		
4	44	66		89	63
8	34	76		90	68
N	29	80		94	56
4	79	62		85	62
8	85	55		90	58
MT	90	53		92	54
Dec. 27			Feb. 25		
4	76	55		87	52
8	68	60		80	54
N	60	64		48	70
4				39	78
8				66	67
MT				79	64

Table 4. Daily fluctuations in temperature, relative humidity and vapour pressure deficit, for periods in May, July and Decemmber 1971, and February 1972. (recorded below Stevenson's screen).

TIME	11-14 May T °F	RH %	VPD mm	26-29 Jul T °F	RH %	VPD mm	14-18 Dec T °F	RH %	VPD mm	24-26 Dec T °F	RH %	VPD mm	29Jan-4 Feb T °F	RH %	VPD mm
N	66	53	7.6	50	87	1.1	68	62	6.9	66	57	7.0	67	62	7.0
4	55	70	3.2	48	93	0.4	78	46	13.0	64	60	7.0	72	49	10.2
8	40	95	0.3	36	93	0.5	64	74	4.0	60	63	5.1	65	61	6.1
MT	44	85	1.2	32	89	0.4	58	83	2.0	53	87	0.9	55	82	2.2
4	48	86	1.3	32	89	0.4	58	88	1.2	53	87	0.9	51	87	1.4
8	50	87	1.3	36	90	0.5	61	84	1.9	68	76	3.5	63	55	6.2
N	64	70	4.5	52	75	2.3	68	62	6.8	78	46	11.9	78	43	13.0
4	54	82	2.1	55	70	3.2	74	50	10.5	84	35	20.0	80	38	16.0
8	52	87	1.0	44	93	0.7	56	88	1.1	71	60	7.0	70	55	8.1
MT	51	94	0.5	36	91	0.5	56	88	1.1	64	65	6.0	59	78	3.0
4	50	95	0.4	32	89	0.4	56	88	1.1	66	44	9.0	58	83	1.9
8	42	77	1.5	36	89	0.5	62	74	3.1	70	34	11.5	60	89	1.2
N	68	62	6.8	48	93	0.4	68	54	7.9	80	29	16.5	78	53	10.5
4	52	75	2.2	48	93	0.4	68	54	11.5	62	79	3.0	78	53	10.5
8	48	79	1.8	45	93	0.3	64	70	4.5	55	94	0.5	76	51	11.5
MT	46	93	0.3	44	93	0.3	58	83	2.0	53	94	0.4	62	84	1.8
4	48	93	0.3	42	93	0.3	55	94	0.5	55	76	1.8	60	89	1.2
8	44	85	1.1	42	93	0.3	70	72	5.0	60	68	3.8	61	84	1.9
N	76	59	9.5	44	93	0.3	74	58	8.0	64	60	7.0	74	61	8.3
4							84	49	9.0				78	53	10.5
8							70	59	7.1				73	57	8.8
MT							66	61	6.9				60	73	3.0
4							64	60	6.1				55	82	2.2
8							78	46	13.0				60	94	0.6
N							90	26	24.1				78	53	10.2

Hours per day when VPD higher than 5

May 11-14	Jul. 26-29	Dec. 14-18	Dec. 24-26	Jan. 29-Feb. 4
0-4 hours	0 hours	4-20 hours average 12	10-16 hours average 13	12-16 hours average 14

—— indicates highest VPD each day.

Table 5. Soil temperatures at depths of 10 and 20 cm at three stations; minima and maxima from weekly records at intervals, Feb. 1971 - Jan. 1972.

Depth cm	Temp	Stn A °F	Stn A Time	Stn A Range	Stn B °F	Stn B Time	Stn B Range	Stn D °F	Stn D Time	Stn D Range
				(Feb. 27-Mar. 7)						
10	Min	62	7-8am		59	7-8am		64	7-8am	
	Max	82	5-6pm	20	82	5-6pm	23	85	5-6pm	21
20	Min	68	8-9am		63	8-9am		67	8-9am	
	Max	77	6-7pm	9	80	6-7pm	17	77	6-7pm	10
				(May 11-18)						
10	Min	52	11-12am		46	1-3am		48	2-4am	
	Max	62	3-4pm	10	61	3-4pm	15	62	3-4pm	14
20	Min	55	10-12am		52	2-4am		54	2-4am	
	Max	60	5-6pm	5	62	5-6pm	10	63	5-7pm	9
				(Dec. 1-8)						
10	Min	57	6-7am		54	6-7am		53	6-7am	
	Max	82	4-5pm	25	79	4-5pm	25	80	4-5pm	27
20	Min	62	7-9am		61	7-9am		60	7-9am	
	Max	70	5-7pm	8	74	5-7pm	13	67	5-7pm	7
				(Dec. 14-21)						
10	Min	55	6-7am		-	-		64	6-7am	
	Max	84	4-5pm	29	-	-		85	4-5pm	21
20	Min	68	7-9am		-	-		66	7-9am	
	Max	75	5-7pm	7	-	-		72	6-8pm	6
				(Dec. 23-30)						
10	Min	62	6-7am		56	5-6am		58	5-6am	
	Max	81	4-5pm	19	81	3-4pm	25	80	3-4pm	22
20	Min	66	7-8am		62	6-8am		64	6-8am	
	Max	74	6-8pm	8	78	5-6pm	16	72	5-6pm	8
				(Jan. 9-16)						
10	Min	62	4-6am		63	6-8am		56	3-5am	
	Max	82	5-6pm	20	98	4-6pm	35	90	2-3pm	36
20	Min	54	4-6am		70	8-9am		62	6-8am	
	Max	63	5-7am	9	92	5-7pm	22	70	6-8pm	8

* instrument out of order.

Table 6. Soil temperatures at depths of 5, 10, 20, and 50 cm maxima and minima recorded over one week, 10-17 Feb. 1972, near Stevenson's screen.

Depth(cm)	Temp	°F	Time	°Range
5	Min	64	5-6am	
	Max	86	4 pm	22
10	Min	64	7 am	
	Max	82	5 pm	18
20	Min	70	7-9am	
	Max	77	9pm	7
50	Min	70	-	
	Max	70	-	0

Table 7. Rainfall (mm) at Lincoln and at three localities on Kaitorete Spit monthly and annual totals, 1970, 1971, 1972.

1970	Lincoln	Hammond's	Bayley's	Study site		
J	58	61.3	52.5			
F	19	21.8	14.3			
M	105	116.5	107,5			
A	26	23.5	27.0			
M	76	73.0	67.8			
J	79	63.0	86.3			
J	78	95.5	79.0			
A	33	21.3	28.2			
S	52	55.8	46.0			
O	45	63.3	63.0			
N	56	49.0	32.5			
D	24	39.5	55.8			
Ann. total	651	683.5	657.9			
1971					No.of days	Period measured
J	30.0	23.3	20.3	*16.0	30	Jan1-Feb.1
F	11.8	26.3	20.0	8.0	36	Feb.1-Mar.6
M	22.8	32.3	21.3	20.8	23	Mar.6-29
A	14.0	15.5	21.8	48.8	48	Mar.29-May.11
M	79.3	103.0	68.0	60.1	25	Mayll-Jun.6
J	63.0	86.3	55.5	42.5	28	Jun.6-Jul.4
J	71.4	53.0	53.8	40.4	28	Jul.4-Aug.1
A	24.1	31.5	21.3	44.1	29	Aug.1-30
S	29.1	24.5	27.8	15.3	27	Aug30-Sep.26
O	26.3	24.5	17.8	18.7	29	Sep.26-Oct.25
N	56.9	60.8	65.5	40.9	31	Oct 25-Nov.25
D	17.6	20.3	19.3	12.0	36	Nov.25-Dec.31
Ann. total	446.3	501.3	412.4	367.6		
						*est. figure.
1972						
J	57.7	49.5	49.8	20.0	22	Dec.31-Jan.22
F	22.2	89.5	33.0	12.0	37	Jan.22-Feb.28
M	24.4	25.7	25.0			
A	42.0	75.2	52.3			
M	66.4	80.2	55.6			
J	40.1	59.7	56.5			
J	60.5	46.7	37.3			
A	26.9	50.3	48.8			
S	12.5	19.0	10.5			
O	74.2	102.5	58.5			
N	16.7	27.7	21.3			
D	44.5	33.8	29.5			
Ann. total	488.1	658.5	477.3			

Table 8. Annual rainfall at Kaitorete (Bayley's) and Lincoln, 1964-1972.

Year	Bayley's mm	Lincoln mm
1964	410.0	415.5
1965	547.0	736.2
1966	490.5	658.0
1967	515.2	614.3
1968	701.3	814.0
1969	*364.0	453.0
1970	657.9	651.0
1971	412.4	446.3
1972	477.3	488.1
Totals	4635.6	5276.4
Nine year mean	515.1	586.2

* Record lowest since 1959

Table 9. Wind records at Kaitorete and Lincoln, 1971.

Kaitorete Period measured	Miles run	Miles per day (monthly mean) Month	Kaitorete	Lincoln
Jan-	-----	J	134 (est)	162
Feb 27- Mar 6	932.2	F	133	150
Mar6 - Apr 12	4005.7	M	125	152
Apr 12- May 11	3442.9	A	115	129
May 11- Jun 6	2076.3	M	106	130
Jun 6- Jul 4	2838.3	J	81	102
Jul 4- Aug1	1563.8	J	70	113
Aug 1- Aug 30	5293.7	A	114	134
Aug 30- Sep 28	4633.9	S	149	184
Sep 28- Oct25	5025.5	O	173	178
Oct 25- Nov 25	5585.7	N	153	178
Nov 25- Dec 23	3550.0	D	126	159
		Sum of means	1486	1771
		Annual monthly mean	123	148

Table 10. Wind velocity at four heights, at microstations, 28 Feb. 1972.
(air-meter read at 5-minute intervals)

Wind SW.		Metres run per five minutes at each height			
Station	Time	Surface	10 cm	30 cm	60 cm
A	12.15pm	*	250	820	1250
B	1.15pm	450	640	1080	1100
C	3.0pm	550	950	1400	2450
D	2.15pm	320	600	1000	2000

* unmeasurable on account of eddy

Table 11. Frequency of surface wind directions (annual %) at Lincoln, 1970-72.

	N	NE	E	SE	S	SW	W	NW	Calm
1970	18.8	25.4	1.1	5.9	12.2	16.6	2.3	12.8	4.9
1971	32.2	10.9	2.1	3.3	15.0	12.4	8.5	8.7	6.9
1972	19.5	25.4	5.5	2.5	12.1	12.3	7.1	11.0	6.6
three year average	23.5	19.9	2.9	3.9	13.1	13.7	5.9	10.8	7.4

Table 12. Evaporation: volumes of water lost from evaporimeters at four stations, 7 Sep. 1971–12 Mar. 1972.

vol. ml.

		Stn A		Stn B		Stn C		Stn D	
Date	Days	Total	Daily av.	Total	Daily av.	Total	Daily av.	Total	Daily av.
Sep7–10	3	100	33	125	42	100	33	100	33
Sep10–26	16	1020	64	1290	81	1050	66	1065	67
Sep26–Oct15	19	1425	73	–	–	1600	84	–	–
Oct15–30	15	1090	73	–	–	1200	80	–	–
Oct30–Nov13	14	985	70	1370	98	1065	76	–	–
Nov13–25	12	875	73	1145	95	835	70	–	–
Nov25–Dec1	6	655	109	840	140	735	122	–	–
Dec1–14	13	1020	78	1370	105	980	75	–	–
Dec14–27	13	1045	80	1450	112	1060	82	–	–
Dec27–Jan 9	13	1240	95	–	–	1261	97	1405	108
Jan9–22	13	1265	97	1339	130	1190	92	1615	124
Jan22–Feb 8	15	1050	70	1540	103	1085	72	1560	104
Feb13–20	7	500	71	630	90	465	65	635	91
Feb20–28	8	470	59	565	71	500	62	565	71
Feb28–Mar12	12	1160	97	1350	113	1190	99	1410	117
Total	179	13740	76	–	–	14206	79	–	–
From Jan9	55	4445	80	5424	98	4420	81	5785	105

NOTE: – indicates instrument out of order.

Table 13 a. Evaporation (monthly) from raised pan at Lincoln, 1970, 1971, 1972,

	1970	1971	1972
J	192	156	214
F	169	160	141
M	153	132	152
A	82	61	74
M	38	33	44
J	42	22	32
J	53	29	30
A	38	36	57
S	90	92	113
O	125	149	119
N	160	163	154
D	218	204	152
annual total	1316	1246	1265

Table 13 b. Hours of sunshine at Lincoln, 1971(monthly).

J	173
F	208
M	205
A	166
M	101
J	82
J	105
A	122
S	169
O	214
N	208
D	205
total	1955

Table 14.

CLIMATOLOGICAL TABLE

LINCOLN

Lat 43 38 LONG 172 30 HT 36 FT

Based on Observations 1881-1960 Unless Otherwise Stated

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
TEMPERATURE - DEGREES F														
MEAN	1944-60	60.9	61.5	57.8	52.8	47.1	42.3	41.4	44.0	48.0	51.8	55.6	58.3	51.8
MEAN DAILY MAXIMUM		71.5	71.9	67.6	62.3	56.2	51.2	50.5	53.2	58.3	62.0	66.7	68.4	61.7
MEAN DAILY MINIMUM		50.2	51.1	48.0	43.3	38.2	33.4	32.3	34.8	37.8	41.7	44.5	48.1	42.0
MEAN DAILY RANGE		21.3	20.8	19.6	19.0	18.0	17.8	18.2	18.4	20.5	20.3	22.2	20.3	19.7
MEAN DAILY GRASS MINIMUM		45.3	45.8	42.2	37.3	32.5	28.2	27.3	29.7	32.3	37.1	39.5	42.8	36.7
MEAN MONTHLY MAXIMUM	1944-60	88.1	88.8	84.7	77.6	69.0	62.1	62.3	64.8	72.1	77.2	81.1	83.8	90.8
MEAN MONTHLY MINIMUM	1944-60	38.0	37.2	34.4	29.2	26.0	22.7	21.8	23.4	26.4	30.1	31.9	36.1	20.4
HIGHEST MAXIMUM		100.2	97.4	93.6	84.9	81.0	72.9	69.0	72.0	88.0	87.2	91.0	98.4	100.2
LOWEST MINIMUM		30.7	32.5	28.5	24.1	21.0	18.9	11.1	19.5	19.0	21.4	27.2	29.8	11.1
EARTH TEMPERATURES AT 9AM														
1 FOOT	1943-60	63.3	63.2	60.1	54.9	49.4	44.4	42.5	44.0	47.6	51.8	56.5	60.6	53.2
3 FEET	1943-60	60.6	61.5	60.0	56.6	52.4	48.2	45.4	45.4	47.5	50.6	54.3	58.0	53.4
RELATIVE HUMIDITY - %														
MEAN AT 9AM		63	65	73	79	84	83	85	82	72	68	64	66	74
BRIGHT SUNSHINE - HOURS														
MEAN	1935-60	221	184	181	141	124	112	122	141	169	191	209	209	2004
PERCENTAGE OF POSSIBLE		49	49	49	45	43	44	45	46	50	48	49	45	47
RAINFALL - INCHES														
MEAN	1921-50	2.2	1.9	1.8	1.7	2.7	2.7	2.3	2.3	1.9	2.0	2.0	2.6	26.1
NUMBER OF RAINDAYS		9	8	10	10	12	12	11	10	10	10	10	10	122
MAXIMUM DAILY RAINFALL		3.84	4.03	3.61	3.10	3.11	4.16	3.20	2.36	1.84	2.55	2.00	2.45	4.15
SPECIAL PHENOMENA - MEANS														
DAYS OF SNOW		-	-	-	-	0.1	0.1	0.9	0.6	0.3	0.1	-	-	2.1
DAYS OF HAIL		0.4	0.1	0.2	0.1	0.3	0.5	0.5	0.5	0.5	0.4	0.4	0.3	4.3
DAYS OF THUNDER		0.7	0.3	0.3	0.1	-	-	-	0.1	0.1	0.3	0.6	0.6	3.1
DAYS OF FOG		0.2	0.3	0.8	1.0	1.7	1.7	1.6	1.4	0.7	0.2	0.2	0.1	9.9
DAYS OF GROUND FROST		0.3	0.4	2.1	5.7	11.5	16.5	18.2	15.5	9.8	5.3	2.3	1.0	88.6
DAYS OF FROST IN SCREEN		-	-	0.2	1.0	4.6	9.4	11.2	7.8	3.2	1.0	0.2	-	38.6
WIND MILES RUN (20FT)														
MEAN		241	243	218	180	173	157	148	179	212	241	229	223	204
EVAPORATION (TANK, R.F.O. 87*) inches														
MEAN	1945-55	5.9	5.0	3.8	2.1	1.3	0.8	0.8	1.5	2.6	3.4	4.7	5.2	37.2

R.F. = * reduction factor to open water evaporation

Table 15.

N.Z. METEOROLOGICAL SERVICE

CLIMATOLOGICAL TABLE

CHRISTCHURCH — LAT 43 32 LONG 172 37 HT 22FT

BASED ON OBSERVATIONS 1905–1960 UNLESS OTHERWISE STATED

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
TEMPERATURES – DEGREES F														
MEAN		61.5	61.1	58.2	53.6	47.7	43.2	42.3	44.4	48.9	53.1	56.5	59.8	52.5
MEAN DAILY MAXIMUM		70.3	69.6	66.5	62.0	55.9	51.3	50.2	52.5	57.5	62.2	65.8	68.7	61.0
MEAN DAILY MINIMUM		52.7	52.6	49.9	45.3	39.6	35.4	34.5	36.9	40.3	44.1	46.5	50.8	44.0
MEAN DAILY RANGE		17.6	17.0	16.6	16.7	16.3	15.9	15.7	15.6	17.2	18.1	19.3	17.9	17.0
MEAN DAILY GRASS MINIMUM		47.3	47.1	44.2	38.9	33.6	29.4	28.8	30.2	33.9	37.7	40.8	45.2	38.1
MEAN MONTHLY MAXIMUM		86.5	84.5	82.0	76.0	69.0	62.7	61.7	65.2	71.2	75.2	79.9	84.2	90.0
MEAN MONTHLY MINIMUM		41.7	41.1	37.2	32.8	28.3	26.1	25.8	26.6	29.7	32.7	36.0	40.0	24.9
HIGHEST MAXIMUM 1.		97.0	95.3	90.4	83.2	79.7	69.3	70.0	72.6	81.1	87.8	90.0	92.3	97.0
LOWEST MINIMUM 1.		34.0	34.2	30.4	25.6	21.3	21.5	19.3	23.0	23.3	26.0	29.8	33.0	19.3
EARTH TEMPERATURES AT 9AM														
1 FOOT		67.4	66.4	62.2	56.3	49.4	43.3	41.3	43.9	48.7	54.8	61.2	64.6	55.0
4 FEET		65.3	65.5	63.8	58.8	53.1	47.4	44.3	45.3	48.9	53.4	58.8	62.4	55.6
RELATIVE HUMIDITY – %														
DAILY MEAN 2.		74	74	78	79	83	83	84	81	77	76	73	74	78
MEAN AT 9AM		67	71	77	83	86	88	88	84	74	67	64	67	76
BRIGHT SUNSHINE – HOURS														
MEAN	1935–60	215	182	174	143	133	116	126	145	169	187	206	194	1990
PERCENTAGE OF POSSIBLE		48	48	48	46	47	45	46	47	50	47	49	42	47
RAINFALL – INCHES														
MEAN	1921–50	2.2	1.8	1.7	1.8	3.0	2.7	2.4	2.3	2.0	2.0	2.0	2.4	26.3
NUMBER OF RAINDAYS		10	8	9	10	12	13	14	11	10	11	10	11	129
MAXIMUM DAILY RAINFALL 3.		3.23	3.07	3.16	4.71	4.00	2.94	2.79	3.25	2.21	2.72	1.80	2.50	4.71
SPECIAL PHENOMENA – MEANS														
DAYS OF SNOW		–	–	–	–	0.2	0.6	1.0	0.5	0.3	0.2	–	–	2.8
DAYS OF HAIL		0.4	0.1	0.2	0.5	0.5	0.6	0.9	0.9	0.9	0.4	0.5	0.4	6.3
DAYS OF THUNDER		0.8	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.5	0.7	3.5
DAYS OF FOG		0.2	0.1	0.2	2.5	4.6	5.2	4.4	3.1	1.2	0.4	0.5	0.4	22.8
DAYS OF GROUND FROST		0.2	0.3	1.2	4.9	11.3	17.4	19.0	17.0	10.0	5.5	2.6	0.6	90.0
DAYS OF FROST IN SCREEN		–	–	–	0.7	3.7	9.8	11.3	8.2	2.5	0.4	0.1	–	36.7
WIND 4.														
DAYS WITH GUSTS 40MPH OR MORE	1942–64	5.7	5.0	5.0	3.8	4.1	3.4	3.4	2.5	4.3	5.8	6.6	5.0	54.6
DAYS WITH GUSTS 60MPH OR MORE	1942–64	0.3	0.2	0.4	0.4	0.2	0.2	0.2	–	0.4	0.3	0.3	0.2	3.1

4. WIND SUMMARY – PERCENTAGE FREQUENCY 1942–50
FROM HOURLY MEAN WINDS AT 3-HOUR INTERVALS

	N	NE	E	SE	S	SW	W	NW	CALM AND 1 – 3 MPH
SPEED 4 – 15 MPH	3.3	10.1	19.8	0.7	6.2	11.5	7.3	3.0	23.8
16 – 31 MPH	0.8	0.7	2.7	–	2.7	3.4	1.2	2.2	
OVER 31 MPH	0.1	–	–	–	0.1	0.1	0.1	0.2	
TOTAL	4.2	10.8	22.5	0.7	9.0	15.0	8.6	5.4	

1. refers to observations 1864–1880, 1905–1960.
2. Wigram Airfield data.
3. refers to observations 1864–1884, 1894–1960.
4. Christchurch Airport wind data.

Table 16.

Wind Frequencies (as a percentage of all windy days)

	SW	W	NW	N	NE	E	SE	S	Calm	Gales(days)
Lincoln (1930–1950)	24	6	12	13	29	3	4	9	21	5

Length of Drought

	up to 5 weeks	over 5 weeks	over 6 weeks	over 7 weeks	over 9 weeks	no. of droughts	average length (days)
Christchurch (69 years)	40	60	34	17	5	96	43

Evapotranspiration (Thornthwaite)

	Height a.s.l. (ft.)	Moisture index	Potential Evapotranspiration for year (in.)	Water deficiency (in.)	Water surplus (in.)	Climatic class
Lincoln	36	6.9	25.2	2.1	3.0	Subhumid mesothermal 'I'

Ellesmere Annual Rainfall ca. 22.6

Days of Fog 15–20

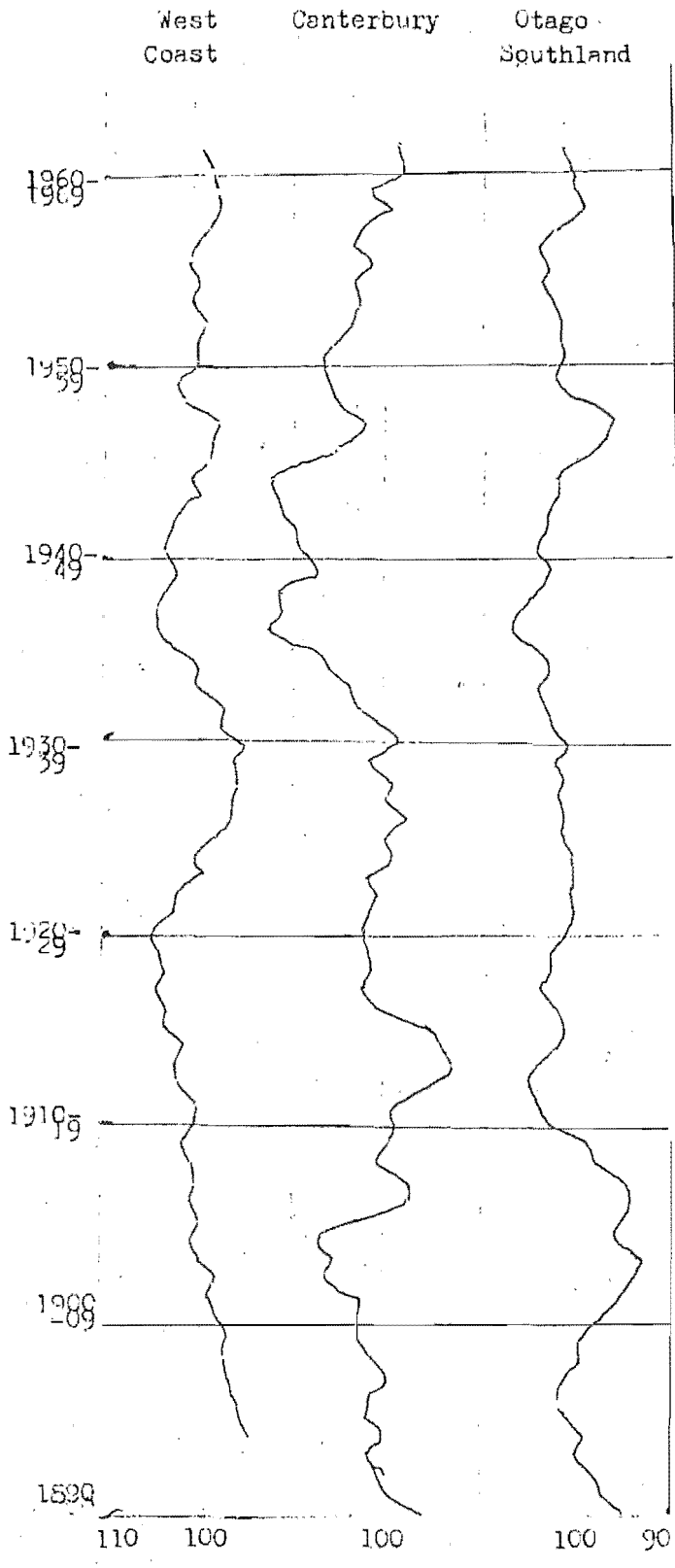


Table 17. Ten year running means of rainfall indices.

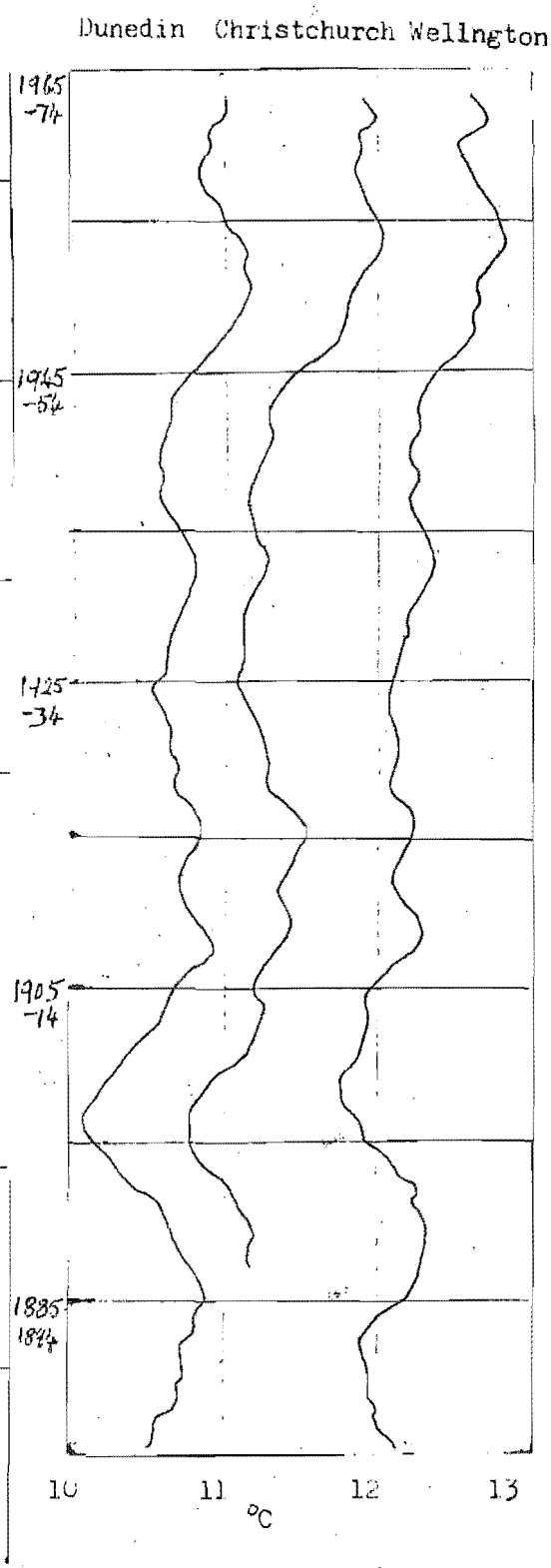


Table 18. Long term changes of average temperature (ten year averages of mean temperatures)

(from J.D. Coulter, N.Z. Meteorological Service)

APPENDIX III

PLANTS

Table 1. Percentage cover at sites comparable to A,B,C,D,E. recorded 9 Dec. 1971.

Species	F	G	H	I	J
Aira caryophyllea					1.5
Bromus diandrus			0.9		3.5
Lagurus Ovatus	5.0	0.5	5.7	9.0	8.7
Notodanthonia unarede				2.7	9.2
Poa laevis					6.0
Stipa variabilis				4.7	10.2
Zoysia minima	*			9.2	
Desmoschoenus spiralis	12.0	0.5	15.5		
Acaena ovina				1.0	5.0
Calystegia soldanella			1.5		*
Carmichaelia appressa			*	0.7	6.7
Cyathodes fraseri					1.0
Hypochaeris radicata	1.7	0.7	1.5	1.2	2.0
Muehlenbeckia complexa			10.0		
Raoulia australis		4.7	7.0		
Rumex acetosella	*		1.2	6.5	4.5
Scleranthus uniflorus		0.2			
Trifolium arvense				2.7	2.2
Triquetrella papillata					9.0
Bare surface	70.2	83.2	55.2	38.2	8.7
Litter	11.6	10.0	8.5	16.7	21.5

F fore dune; G blowout; H rear dune; I sandy flat; J old dune

* indicates species occurring too rarely to be recorded.

CHECKLIST OF PLANT SPECIES MENTIONED IN THE TEXT

(Ad = adventive)

SHRUBS AND SUB-SHRUBS

Carmichaelia appressa	Prostrate broom
C. corrugata	Dwarf broom
Clematis afoliata	Leafless clematis
Coprosma propinqua	Miki miki
Cytisus scoparius Ad	Broom
Discaria toumatou	Matagouri
Dodonea viscosa	Akeake
Hymenanthera alpina	Porcupine bush
Lupinus arboreus Ad	Yellow lupin
Muehlenbeckia astonii	Pohuehue
M. complexa	"
M. ephedrioides	"
Myoporum laetum	Ngaio
Pimelea prostrata	N.Z. daphne
Rosa rubiginosa Ad	Sweet brier
Ulex europaeus Ad	Gorse
Rhagodia triandra	

FORBS

Acaena ovina Ad	Sheeps burr
A. novae-zelandiae	Bidi-bidi
Calystegia soldanella	Sand convolvulus
Convolvulus erubescens	
Cerastium glomeratum Ad	Mouse-eared chickweed
Craspedia lanata	Woollyhead
Cyathodes fraseri	Patotara
Dichondra repens	Mercury Bay weed
Hypochaeris radicata Ad	Catsear
Leontodon taraxicoides Ad	Hawkweed
Lepidium murale	Dune cress
Raoulia australis	Scabweed
Rumex acetosella Ad	Sorrel
Scleranthus uniflorus	Kohukohu
Silene gallica Ad	Catchfly
Trifolium arvense Ad	Haresfoot trefoil
Vittadinia australis	

GRAMINOIDS

Aira caryophyllea Ad	English hairgrass
Ammophila arenaria Ad	Marram grass
Bromus diandrus Ad	Barren brome
Carex breviculmis	
C. pumila	Sand sedge
Desmoschoenus spiralis	Pingao
Lagurus ovatus Ad	Harestail grass
Notodanthonia unarede	Danthonia
Poa laevis	Silver tussock
P. pratensis Ad	Kentucky bluegrass
Stipa variabilis Ad	Needlegrass
Zoysia minima	Pygmy twitch
Scirpus nodosus	

OTHERS

Pteridium esculentum	Bracken fern
Hypnum cupressiforme	Moss
Triquetrella papillata	"
Parmelia cf. conspersa	Lichen
P. cf. olivacea	"
Ramalina sp.	"
Teloschistes sp.	"
Usnea sp.	"

REFERENCES

Acland, L.D.G. 1951. The Early Canterbury Runs. Christchurch.

Allan, H.H. 1961. Flora of New Zealand, Vol. I. Govt. Printer, Wellington.

Armon, J.W. 1970. Recent shorelines between Banks Peninsula and Cooper's Lagoon. M.Sc. Thesis, University of Canterbury.

Bagnold, R.A. 1941. The Physics of Blown Sand and Desert Dunes. Methuen, London.

Beadle, N.C.W. 1962. Soil phosphate and delimitation of plant communities in Eastern Australia. Ecol. 43: 281-288.

Birand, H. 1961. Relations entre le de'velloppement des racines et des parties ariennes chez certaines plantes xerophytes, et leur resistance a la secheresse. Proc. Madrid Symposium on Arid Zone Research XVI, p.175 (U.N.E.S.C.O.).

Boyce, S.G. 1954. The salt spray community. Ecol. Mon. 24: 29-67.

Braun-Blanquet, J. 1932. Plant Sociology: the study of plant communities. (Translated and edited by G.D. Fuller and H.C. Conard). McGraw-Hill Book Co. Inc., New York.

Brawand H. and H. Kohnke, 1952. Microclimate and water vapour exchange at the soil surface. Proc. Am. Soc. Soil Sc. p.145-8.

Burrows, C.J. 1969a. A Handbook of Background Material to the Ecology of the Lake Ellesmere Area. Univ. of Canterbury.

———— 1969b. The Flora and Vegetation of Kaitorete (Ellesmere) Spit. J.Cant.Bot.Soc. No. 2.

Butterfield, G.R. 1971. The instrumentation and measurement of wind erosion. Reprint from Proc. Sixth Geog.Conf. N.Z. Geog.Soc., Christchurch.

Chapman, V.J. 1964. Coastal Vegetation. Pergamon Press, McMillan Co., New York.

Clements, F.E. 1936. Nature and Structure of the climax. J.Ecol. 24: 252-284.

Cockayne, L. 1911. Report on the dune areas of New Zealand. Dept. Lands and Survey, Parliamentary Paper C13, Wellington.

———— 1928. The Vegetation of New Zealand (2nd Ed.) Engelmann, Leipzig.

———— 1967. New Zealand Plants and their Story. (4th Ed.) edited by E.J. Godley. Govt. Printer, Wellington.

Colinvaux, P.A. 1972. An introduction to Plant Ecology. Wiley and Sons, New York.

Cowles, H.C. 1899. The ecological relations of the vegetation of the sand dunes of Lake Michigan. Bot.Gaz., 27: 95-117; 167-202; 281-308; 361-391.

Cumberland, K.B. 1962. Climatic change or cultural interference. Land and Livelihood: Geographical essays in honour of George Jobberns, p.88-142. ed. Murray McCaskill, Christchurch.

Daubenmire, R. 1947. Plants and Environment. Wiley and Sons, New York.

———— 1968. Plant Communities. Harper and Row, London.

de Lisle, J.F. 1969. The Climate and Weather, in Natural History of Canterbury, ed. G.A. Knox, A.H. and A.W. Reed, Wellington.

Duvdevani, S. 1957. Dew research for arid agriculture. Discovery 18: 330-384.

Emberger, L. and G. Lemee. 1962. Problems of the arid zone. Proc. Paris Symposium on Arid Zone Research XVIII. U.N.E.S.C.O.

Esler, A.E. 1969. Manawatu sand plain vegetation. Proc. N.Z. Ecol. Soc. 16: 32-35.

———— 1970. Manawatu sand dune vegetation. Proc. N.Z. Ecol. Soc. 17: 41-46.

Eyre, S.R. Vegetation and Soils: a world picture. Edward Arnold Ltd., London.

Foweraker, C.E. 1917. Mat plants, cushion plants and allied forms of the Cass river-bed. Trans. N.Z. Inst. 49: 1-45.

Gardner, W.R. 1960. Soil water relations in arid and semi-arid conditions. Proc. Paris Symposium on Arid Zone Res. XV. U.N.E.S.C.O.

Garnier, B.J. 1958. Climate of New Zealand. Edward Arnold Ltd., London.

Geiger, R. 1965. The Climate Near the Ground. Revised ed. Harvard University Press, Massachusetts.

Glover, P.E., J. Glover and M.D. Gwynne. 1962. Light rainfall and plant survival in East Africa. II. Dry grassland vegetation. J.Ecol. 50.

Goodall, D.W. 1952. Some considerations in the use of point quadrats for analysis of vegetation. Aust. J.Sci.Res.

———— 1953. Objective methods for classification of vegetation, II. Fidelity and indicator value. Aust. J.Bot. 1: 434-456.

Grieg-Smith, P. 1964. Quantitative Plant Ecology. 2nd ed. Butterworth, Washington D.C.

Harris, W. 1968. A study of the variation and ecology of Rumex acetosella. Ph.D. Thesis, Univ. of Canty.

Hassouna, H.G. and P.F. Wareing. 1964. Possible role of rhizosphere bacteria in nitrogen-fixation of Ammophila arenaria. Nature, 202: 467.

Healy, A.J. 1969. The adventive flora of Canterbury, in The Natural History of Canterbury. edit. G.A. Knox, A.H. and A.W. Reed, Wellington.

Henkel, D.A. 1961. Drought resistance in plants: methods of recognition and intensification. Proc. Madrid Symposium on Arid Zone Research XVI. U.N.E.S.C.O.

Henrici. 1942. ex Oppenheimer, 1960.

Holloway, J.T. 1954. Forests and climates in the South Island of New Zealand. Trans. R.Soc.N.Z. 82: 329-410.
———— 1964. The forests of the South Island: the status of the climatic change hypothesis. N.Z. Geographer, 20: 1-9.

Killian. 1942. ex Oppenheimer, 1960.

Knox, G.A. 1969. Beaches: in The Natural History of Canterbury, ed. Knox G.A. A.H. and A.W. Reed, Wellington.

Kramer, P.J. 1949. Plant and Soil Water Relationships. McGraw Hill, New York.

Landsberg, S.Y. 1956. The orientation of dunes in Britain and Denmark in relation to wind. Geog.J.122: 176-189.

Lebedeff, A.F. 1928. Movement of ground and soil waters. Proc. First International Congress on Soil Science. Vol. 1., 459-494.

Lemee. 1954. ex Oppenheimer, 1960.

Levitt, J. 1956. The Hardiness of Plants. Academic Press, New York.

Logan, M.C. and E.J. Holloway. 1934. Plant succession on Oreti River sand dunes. Trans. Roy.Soc. N.Z.

Martin, W.E. 1959. The vegetation of Island Beach State Park, New Jersey. Ecol. Mon. 29: 1-46.

McIndoe, K.G. 1932. An ecological study of the vegetation of the Cromwell district with special reference to root habit. Trans. N.Z. Inst. 62.

Marshall, J.K. 1965. Corynephorus canescens as a model for the Ammophila problem. J.Ecol. 53: 447-463.

Molloy, B.P.J. et al. 1963. Distribution of sub-fossil forest remains, Eastern South Island. N.Z. J.Bot. 1: 68-77.

Moore, P.D. 1971. Computer analysis of sand dune vegetation in Norfolk, England, and its implications for conservation. Vegetatio, 23: 323-338.

Moore, L.B. and E. Edgar. 1970. Flora of New Zealand. Vol. II. Govt. Printer, Wellington.

Olson, J.S. 1958a. Rates of succession and soil changes on Southern Lake Michigan sand dunes. Bot.Gaz. 119: 125-170.

———— 1958b. Lake Michigan sand dune development. I. Wind velocity profiles. J.Geol. 66: 254-263.

Olsson-Seffer, P. 1909. Hydrodynamic factors influencing plant life on sand sea-shores, New Phytol., 8: 37-49.

Oosting, H.J. 1945. Tolerance of salt spray by plants of coastal dunes, Ecol. 26: 85-89.

———— 1954. Ecological processes and vegetation of the maritime strand in the United States, Bot.Rev., 29: 226-262.

Oosting, H. J., and W.D. Billings, 1942. Factors affecting vegetational zonation on coastal dunes, Ecol. 23: 131-142.

Pegg, E.J. 1913. Ecological study of some N.Z. sand dune plants. Trans. N.Z. Inst. XLVI.

Oppenheimer, H.R. 1951. Summer drought and water balance of plants growing in the Near East. J.Ecol., 39: 356-362.

———— 1960. Adaptations to drought: Xerophytism; Plant-water relations in arid and semi-arid conditions. Reviews of Research, Paris Symposium on Arid Zone Research XV. p.105-138.

Poore, M.E.D. 1956. The use of phytosociological methods in ecological investigations, J.Ecol., 44: 28-50.

Radcliffe, J.E. and N.S. Mountier. 1964. Problems in measuring pasture composition in the field. N.Z. J.Bot., 2.2.

Ranwell, D.S. 1958. Movement of vegetated sand dunes at Newborough Warren, Anglesey. J.Ecol., 46: 83-100.

———— 1959. Newborough Warren, Anglesey. I. The dune system and dune slack habitat. J.Ecol., 47: 571-601.

———— 1960a. Newborough Warren, Anglesey. II. Plant associes and succession cycles of the sand dune and dune slack vegetation. J.Ecol., 48: 385-395.

Ranwell, D.S. 1960b. Newborough Warren, Anglesey. III. Changes in the vegetation on parts of the dune system after the loss of rabbits by myxomatosisis. J.Ecol. 49: 325-340.

———— 1972. Ecology of Salt Marshes and Sand Dunes., Chapman and Hall, London.

Ramdas, L.A., and M.S. Katti. 1934. Preliminary study on soil moisture in relation to moisture in surface layers of the atmosphere during a clear season at Poona, India. J.Agr.Sc., 4: 923-937.

Salisbury, E.J. 1925. A note on the edaphic succession in some dune soils, with special reference to the time factor. J.Ecol., 13: 322-8.

———— 1952. Downs and Dunes: their plant life and its environment. Bell, London.

Shields, L.M. 1950. Leaf xeromorphy as related to physical and structural influences. Bot.Rev., 16: 175-190.

Slatyer, R.O. 1961. Methodology of a water balance study in a desert woodland (Acacia aneura) woodland in Central Australia. Proc. of Madrid Symposium on Arid Zone Research XVI. U.N.E.S.C.O.

———— 1967. Plant Water Relationships. Academic Press, London.

Stocker, O. 1960. Physiological and morphological changes in plants due to water deficiency. Proc. Paris Sym. Arid Zone Res. XV. U.N.E.S.C.O.

Stone, E.C. 1957. Dew as an ecological factor, a review of the literature. Ecol., 38: 401-413.

Suggate, R.P. 1958. Late quaternary deposits of the Christchurch metropolitan area. N.Z. J. of Geol. and Geophysics 1: 103-102.

———— 1963. The fan surfaces of the Central Canterbury Plain. N.Z. J.of Geol. and Geophysics 6: 281-287.

Thornethwaite, C.W., and J.R. Mather. 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Publications in Climatology Vol. 10, No. 3. Drexel Inst. of Technology, New Jersey.

Tinklin, R. and D.J.F. Bowling. 1968. The water relations of bracken - a preliminary study. J.Ecol., 56: 669-671.

Wall, A. 1930. The plant covering of the Spit; Appendix to Speight R. The Lake Ellesmere Spit. Trans. N.Z.Inst. p.61-147.

Wardle, P. 1963.

Watt, A.S. 1957. The effect of excluding rabbits from grassland in Breckland. J.Ecol. 45: 861-78.

Weaver, J.E. 1958a. Classification of root systems of forbs of grassland and a consideration of their significance. Ecol. 39: 391-401.

———— 1958b. Summary and interpretation of underground development in natural grassland communities. Ecol. Mon. 28: 55-78.

Wells, B.W. and I.V. Shunk. 1931. The vegetation and habitat factors of the coarser sands of North Carolina coastal plain. Ecol. Mon. 1: 465-520.

———— 1937. Seaside shrubs: wind forms versus spray forms. Science, 85: 499.

Went, F.W. 1949. The ecology of desert plants. II. The effect of rain and temperature on germination and growth. Ecol. 30: 1-13.

Whitehead, F.H. 1962. Experimental studies on the effect of wind on plant growth and anatomy., I and II New Phytol. 61: 56-62.

———— 1963. ibid. III and IV: New Phytol. 62: 80-86.

Whittaker, R.H. 1953. A consideration of the climax theory. Ecol. Mon. 23: 41-78.

———— 1962. Classification of natural communities. Bot.Rev. 28: 1-239.

Williams, O.B. 1956. Studies in the ecology of the reverine plain.

Willis, A.J., Folkes, B.F., Hope-Simpson J.F. and Yemm, E.W. 1959. Braunton Burrows: the dune system and its vegetation. I and II. J.Ecol. 47: 1-24 and 249-288.

Willis, A.J. and E.W. Yemm. 1961. Braunton Burrows: Mineral nutrient status of the dune soils. J.Ecol. 49: 377-390.

Wilson, K. 1960. The time factor in the development of soils at South Haven Pen. Dorset, J.Ecol. 48: 341-359.

Wraight, M.J. 1957. The ecology of Lake Ellesmere Spit. M.Agr.Sc. Thesis, Lincoln College, University of Canterbury.

Wright, T.W. 1955. Profile development in sand dunes of Culbin Forest, Morayshire. I. Physical properties, J.Soil Sc. 6: 270-283

———— 1956. Profile development in sand dunes of Culbin Forest, Morayshire. II. Chemical properties, J.Soil Sc. 7:

Zohary, M. 1961. Hydroecological relations of the Near East vegetation. Proc. Madrid Sym. Arid Zone Res. XVI, p.199.

Zotov, V.D. 1963. Synopsis of the grass sub-family Arundinoideae in New Zealand. N.Z. J.Bot. 1: 78-136.

Misc. Methods of Measuring Plant Communities. 1962. Report of a seminar at Cass. N.Z. Inst.Agr.Sc.

N.Z. Meteorological Service Climatalogical Observations at N.Z. Stations. 1960-1972.